Technical Report EL-95-29
October 1995

US Army Corps of Engineers
Waterways Experiment Station

A Habitat Improvement Plan for the Big Sunflower River, Mississippi

by Andrew C. Miller

Prepared for U.S. Army Engineer District, Vicksburg

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Waterways Experiment Station
3909 Halls Ferry Road
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Final report

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Prepared for U.S. Army Engineer District, Vicksburg
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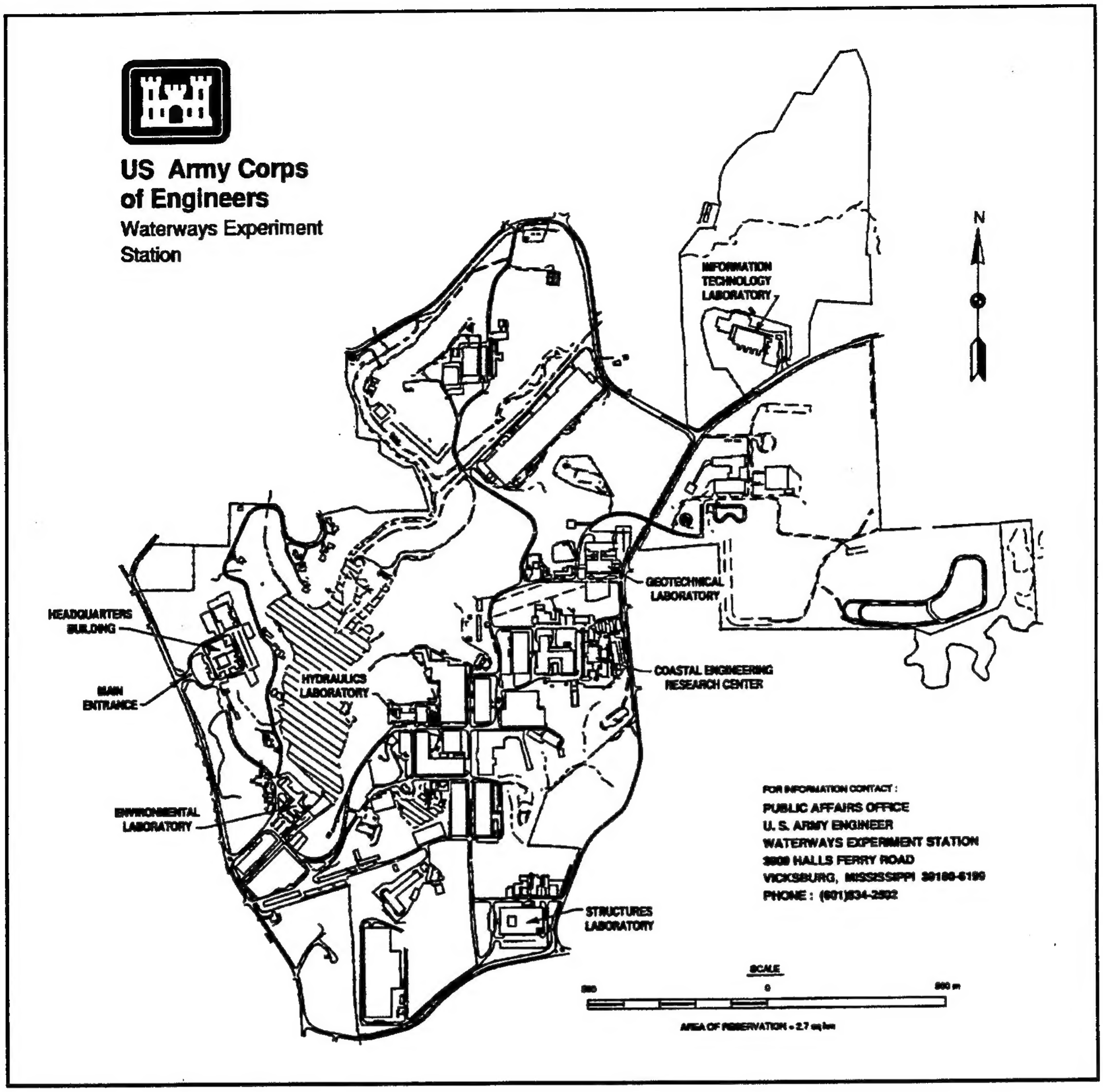

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Preface

In June 1994, personnel of the U.S. Army Engineer District, Vicksburg, requested that personnel of the U.S. Army Engineer Waterways Experiment Station (WES) prepare a habitat improvement plan for the Big Sunflower River, Mississippi. The purpose was to develop a plan to mitigate for adverse effects of planned channel maintenance on freshwater mussels and their habitat. Planned maintenance in the Big Sunflower River would consist of channel clearing and cleanout. The habitat improvement plan described herein was developed cooperatively with personnel of the Vicksburg District; U.S. Fish and Wildlife Service (USFWS); Mississippi Department of Wildlife, Fisheries and Parks (MDWF&P); WES; Department of Biology, University of Southern Mississippi (USM); and Dr. John L. Harris, a malacologist from Arkansas. Information on mussels in the river was obtained from a previous study conducted by WES personnel with the assistance of divers from the Tennessee Valley Authority.

The following individuals provided technical information on the maintenance project and the Big Sunflower River: Messrs. Larry Banks, Tommy Shelton, Frankie Griggs, Ron Goldman, and Lee Robinson. Information on the fishery resources of the project area was provided by Dr. K. Jack Killgore, WES. Mr. Kenneth R. Quackenbush, Fish and Wildlife Biologist, USFWS, provided information on the project area, prepared sections of this report, and assisted with development of the mitigation plan. Messrs. Jack Herring and Garry Lucas, MDWF&P, provided information on the project area and helped to develop the mitigation plan. Information on molluscs and macroinvertebrates was obtained from Drs. John Harris, Shiao Wang, and David Beckett, USM, and Dr. Barry Payne, WES. Background information on materials and equipment required for construction of the habitat improvement features was obtained by Ms. Fawn Burns, Rice University. Dr. Andrew C. Miller, Environmental Laboratory (EL), WES, prepared this report.

During the conduct of this study, Dr. John W. Keeley was Director, EL; Dr. Conrad J. Kirby was Chief, Environmental Resources Division, EL; and Dr. Alfred F. Cofrancesco, Jr., was Chief of the Aquatic Habitat Group, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
tons (mass) per cubic yard	1,328.939	kilograms per cubic meter

1 Introduction

Concern for Mussel Habitat in the Big Sunflower River

Personnel of the U.S. Fish and Wildlife Service and the Mississippi Department of Wildlife, Fisheries and Parks recently expressed concern over the effects of proposed maintenance dredging by the U.S. Army Engineer District, Vicksburg, on freshwater mussels (Family: Unionidae) and their habitat in the Big Sunflower River, Mississippi. Planned maintenance would consist of channel clearing, cleanout, enlargement, and maintenance. Because of these concerns, Vicksburg District personnel modified the original dredging plan to minimize damage to mussels and their habitat. In addition, a Habitat Improvement Team (members of the Team are listed in Table 1) was assembled to review recent findings on mussels, evaluate the effects of dredging, and develop a set of actions that would improve and maintain habitat in river reaches affected by maintenance. These actions would not replace a set of features developed specifically to improve fish habitat (Hoover and Killgore, in preparation).

All team members understood that mussel habitat replacement had never been attempted on such a scale as this before. It was acknowledged that a long time could be required to reestablish habitats affected by dredging. Years could be required to determine if mussel assemblages had been positively affected by improvements. Team members realized that replacing and restoring mussel habitat value must involve holistic planning and execution. This approach must address all aspects of the mussel's life cycle, physical habitat requirements, host fish species, and food availability. Without a broad perspective for planning and implementation, the goal of mitigating loss of habitat value cannot be achieved.

Before the Team discussed various appropriate habitat improvement options for the Big Sunflower River, they prepared a set of goals that would guide the Team. The intent is to maintain and improve habitat for freshwater mussels in portions of the Big Sunflower River to mitigate for expected losses. These goals, which were mutually agreed upon by all, are as follows:

Table 1
Habitat Improvement Team for the Big Sunflower River, Mississippi

Mississippi Department of Wildlife, Fisheries and Parks Mr. Garry Lucus Mr. Jack Herring
U.S. Fish and Wildlife Service Mr. Ken Quackenbush
University of Southern Mississippi Dr. Shiao Wang Dr. David Beckett
Non-Governmental Consultant Dr. John Harris
U.S. Army Engineer District, Vicksburg Mr. Marvin Connon Mr. Steve Reed Mr. Frankie Griggs Mr. Ron Goldman Mr. Larry Goldman Mr. Tommy Shelton Mr. Lee Robinson
U.S. Army Engineer Waterways Experiment Station, Vicksburg Dr. Barry S. Payne Dr. Andrew C. Miller

a. The habitat improvements to the Big Sunflower River would maintain existing mussel species richness (numbers of species) based on those measured in 1993 by Miller and Payne (in preparation). The intent is to improve species diversity and recruitment levels of the community over those measured in the 1993 survey (Miller and Payne, in preparation).

b. The physical structures planned for the Big Sunflower River (dikes, weirs, gravel bars) would be designed to improve overall substratum conditions for the freshwater mussels. In addition, structures would be designed to improve water velocity for freshwater mussels during low flow.

c. Information obtained as a result of monitoring the physical and biological responses of these proposed features can be used to develop habitat improvement measures for other low-gradient rivers in the South.

Project Area

The Big Sunflower River originates near Moon Lake, Coahoma County, flows south through agricultural land, and enters the Yazoo River

between Sharkey and Yazoo counties, Mississippi. The mouth of the Big Sunflower River is at river mile (RM) 0.0. Much of the river can be characterized as low gradient, with steep, poorly vegetated and often eroding banks. Water velocity at low flow in the summer is typically less than 0.5 ft/sec.[1] Substratum throughout the river consists mainly of fine-grained silt and sand. Gravel is uncommon with the exception of a reach immediately upriver of the Holly Bluff Cutoff. Deep deposits of fine sand and silt (often greater than 2 ft) are common along much of the shoreline upriver of abandoned Lock and Dam 1 located at RM 54.6. (All RMs in this report are "improved" and take into account the changes because of the Holly Bluff Cutoff, which caused a loss of 7.4 miles. An exception is the bendway excluded by the Holly Bluff Cutoff; the RMs in the bendway are "unimproved" and identical to those on topographic maps). Throughout much of the river, deep deposits of fine-grained sand and silt are common.

Maintenance history

The most recent channel improvements to the river and its tributaries were done in the 1960s. That project included 47.5 miles of channel clearing, 21.5 miles of channel cleanout, 43.1 miles of channel enlargement, channel cut-offs aggregating 16 miles in channel length, and construction of a weir at the lower end of the Holly Bluff Cutoff to control low-water levels.

Recent flooding in the lower reach of Bogue Phalia and Big Sunflower River necessitated a review of conditions for hydraulic conveyance in the river. Based upon an analysis by the Vicksburg District, the determination was made that channel hydraulic conveyance had deteriorated since completion of the earlier project. District personnel developed a plan to dredge reaches of the Big and Little Sunflower rivers and Bogue Phalia to improve flood conveyance and reduce local flooding. Proposed work will be accomplished mainly with a hydraulic dredge, which has less environmental impact than a dragline. Channel maintenance in the Big Sunflower River will consist of the following:

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1 A table of factors for converting non-SI units of measurement to SI units is presented on page viii.

Big Sunflower River Mile	Type of Action/Amount of Material
0.0 - 6.9	No work[1]
6.9 - 19.2	Channel cleanout - 3- to 85-ft width
19.2 - 26.1	Channel cleanout - 80-ft bottom[2]
26.1 - 26.4	Channel cleanout - 200-ft bottom[2]
26.4 - 26.6	No work[3]
26.6 - 28.4	Channel cleanout - 200-ft bottom[2]
28.4 - 37.9	No work[4]
37.9 - 49.6	Channel cleanout - 3- to 250-ft width
49.6 - 50.2	No work[4]
50.2 - 53.9	Channel cleanout - 3- to 250-ft width
53.9 - 54.1	No work[3]
54.1 - 57.5	Channel cleanout - 3- to 250-ft width
57.5 - 70.6	Channel cleanout - 3- to 250-ft width
70.6 - 75.6	Channel cleanout - 3- to 150-ft width

[1] No flow in this reach - diverted through Six Mile Cutoff.
[2] Restoration of channel to authorized bottom width and grade.
[3] No work reach to avoid high-density mussel bed.
[4] Sufficient channel capacity.

Mussels in project area

A survey to assess community characteristics, density, population demography of dominant species, and the presence of rare, endangered, or threatened species of mussels was conducted in the Big Sunflower River, September-October 1993 (Miller and Payne, in preparation). Results were used to assess the economic value of mussels and to determine the environmental effects of proposed maintenance dredging. Studies were conducted at four beds downriver of abandoned Lock and Dam 1 (RM 54.6 to 26.3) and along a river reach upriver of the dam (54.6 to 141.8). The following is a summary of studies conducted in 1993 (Miller and Payne, in preparation).

At the four beds downriver of the lock and dam, the fauna was dominated by the threeridge (*Amblema plicata plicata*) (49.1 to 90.0 percent), followed by the pimpleback (*Quadrula pustulosa pustulosa*) (2.0 to 19.4 percent), and the bankclimber (*Plectomerus dombeyanus*) (3.5 to 29.0 percent). Species richness at these beds (9 to 12 species) and species diversity (H′, 0.49 to 1.46) were low. Mean density (individuals/square meter) was high and ranged from 28.6 (±2.8, ±Standard Error) to 235.0

(±16.0), and mean biomass (grams/square meter) ranged from 6,590.8 (±636.1) to 52,250.1 (±3,284.8). There was virtually no evidence of recent recruitment for any species; less than 1 percent were less than 30-mm total length. No endangered species were found, although *Pleurobema pyramidatum*, a candidate for inclusion on the Federal list, was collected.

Upriver of abandoned Lock and Dam 1, between RM 54.6 and 141.8, conditions were more depositional than downriver. No high density beds were found in this reach although the majority of areas sampled supported some live mussels. Mean density and collection rate (mussels collected/minute) were 5.5 ± 0.75 and 5.7 ± 0.53 between RM 54.6 and 75.6. Between RM 77.8 and 141.8, density and collection rate were less than in the lower reach, 2.13 ± 0.71 individuals/square meter and 2.2 ± 0.38 individuals were collected/minute.

Maintenance dredging will alter habitat for common and uncommon species in the Big Sunflower River. Mussels in the path of the dredge will likely be killed. Fishes and their habitat could be adversely affected. Commercial harvest will reduce numbers of selected species (mainly *A. p. plicata* and *M. nervosa*). The lack of recent recruitment, dominance of a single species, and low-species diversity make these mussels vulnerable to dredging or commercial harvest.

Purpose

The purpose of this report is to describe actions designed to improve habitat for freshwater mussels, as well as other macroinvertebrates and fishes, at selected sites within the Big Sunflower River Maintenance Project area. These improvements will not fully replace project-related losses of mussels and habitat caused by dredging. Rather, features will be designed to improve physical conditions for mussels at selected locations. Habitat improvement features will be monitored to evaluate the success of methods to restore degraded mussel habitat.

2 Techniques for Habitat Improvement

Important Considerations

Before the Habitat Improvement Team formulated and evaluated habitat improvement features for the Big Sunflower River, they agreed upon the following guidelines:

a. Personnel of the Hydraulics Division of the Vicksburg District will determine the best locations of proposed habitat improvement structures. The Team will provide a recommended reach and only an approximate river mile. An approximate location suggested by the Team could, after evaluation by Hydraulics personnel, be deemed to be inappropriate. Hydraulics personnel could recommend additional or alternative sites based upon results of their analysis.

b. Substratum will be placed in association with proposed weirs and dikes. The Team agreed that for each plan, substratum would be placed at only about 50 percent of the structures. This will be done to allow for an evaluation of the value of the artificially placed substratum for aquatic organisms. The Team agreed that coarse particulate matter (1- to 3-in.-diam gravel) would be appropriate. However, whole or crushed shell, either freshwater or marine, could also be used.

c. Gravel will also be used to increase the areal extent of existing beds that currently support mussels.

d. The Team agreed that underwater structures (fish attractors) should be placed at known beds or on gravel substratum placed near dikes and weirs. Their purpose will be to attract invertebrates and fishes; the latter are important as hosts for most mussels. Some attractors will be placed on the artificially placed gravel, and some attractors would be placed directly on the substratum (with no added gravel) immediately after dredging. The purpose of not placing attractors at

all locations was simply to expand the experimental (or testable) aspects of this project.

e. Mussels from outside the watershed will not be used to reseed artificially placed gravel. In addition, no Endangered or Threatened species will be translocated to any habitat improvement sites in the Big Sunflower River.

f. Mussels will be collected from areas in the Big Sunflower River and used to reseed some of the habitat improvement areas. The Team agreed to design the reseeding program to follow that of the maintenance dredging plan. Since construction proceeds in an upriver direction, so would construction of features for the improvement plan and seeding of mussels. Within the first year of construction, approximately 25 percent of the proposed improvement areas will be seeded with mussels. Within 3 years of construction, another 25 percent of the reaches would be seeded. Therefore, approximately 50 percent of the areas where habitat improvements are planned will be allowed to reseed naturally. As with placement of substratum, this adds to the experimental or testable aspects of this work.

g. A monitoring plan will be prepared to evaluate the ability of physical structures to provide suitable conditions of water velocity and substratum that will favor a rich and diverse assemblage of naturally recruiting freshwater mussels. Monitoring will last for 10 years. The Team agreed that detailed monitoring (for example, assessments of density) may not be needed each year at each structure. All structures could be visually inspected each year, and detailed physical, chemical, and biological studies could be conducted every second or third year.

Proposed Habitat Improvement Features

Proposed structures and combinations of structures for the Big Sunflower River must not be of a height, width, or breath to conflict with project purposes. While this combining of purposes could appear to cause a hydraulic conflict, this is not the case. Structures placed in the lower one-third of the water column seldom affect the discharge of flood or normal flows. Therefore, proposed structural actions to improve mussel habitat will be consistent with project purpose. In addition, structures proposed for the Big Sunflower River should not be visible above the water surface. The following is a brief discussion of habitat improvement features suitable for the Big Sunflower River.

Dikes

A dike is a structure that partially obstructs flow and directs water to the opposite side of the channel or down a new channel. Dikes planned for the Big Sunflower River maintenance project will be constructed of riprap and placed in a field of five or three. Dikes will be approximately 150 ft apart, 100 ft long, and will point upriver (Figure 1). A series of dikes along one river bank that reach approximately one-half of the way across the channel will direct flow to the opposite side of the channel and help keep substratum sediment free. Dike fields are most appropriately used in a gentle bendway, and the field will be oriented so that dikes are tied to the inside bank and direct current to the outside of the bendway.

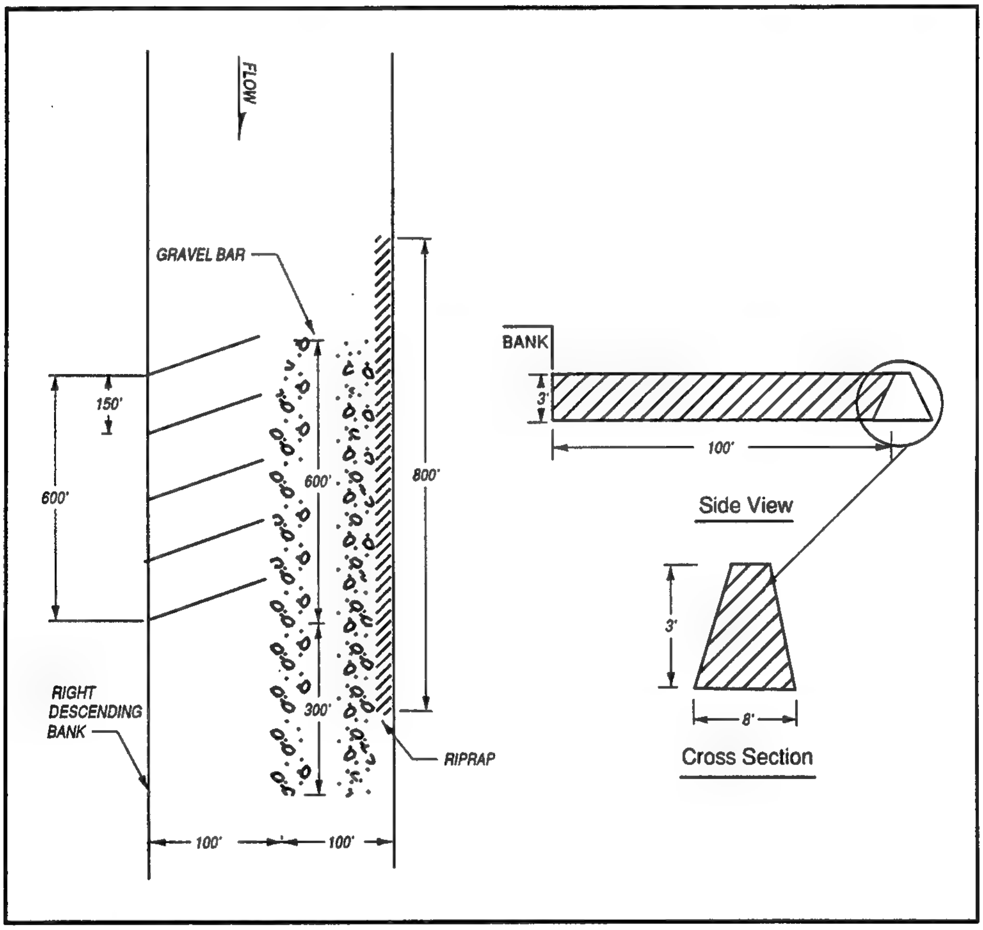

Figure 1. Straight dike field with bank stabilization and associated gravel bar

A dike is a particularly useful habitat improvement feature for mussels in that it provides a velocity regimen that is typically found above firm substratum where high-density mussel assemblages exist. In most navigable and nonnavigable rivers, the densest concentrations of mussels are found between the thalweg and the shore. The channel is usually erosional and not as conducive to settlement and establishment of immature

mussels. Dikes proposed for the Big Sunflower River will direct flow toward the banks, the best mussel habitat.

Typically, current velocities of 0.49 to 1.47 ft/sec (0.15 to 0.45 m/sec) are conducive to establishment and maintenance of mussel beds (unpublished observations by Miller and Payne). Sustained velocity greater than 1.5 ft/sec can erode a mussel bed. Dikes will be used to establish flow regimes and current velocities that are optimum for mussels. The primary objective is to establish current velocities during low-water conditions that will remove excess, fine-grained sediment from the substratum.

Several habitat features will be used in association with the dikes. The bank opposite the dikes will likely have to be stabilized with riprap (Figure 2). Riprap shields the bank from the motion of the river, so less soil is disturbed and erosion is minimized. Because of the large quantity of sand and silt in the watershed, a gravel filter will be required under the riprap. Riprap will extend 100 ft upriver and downriver of the field. Since the five dikes will cover 600 ft, a total of 800 ft of bank will have to be stabilized. If banks are not stabilized, the increased velocity from the field could likely erode the adjacent bank and decrease the value of the substratum immediately downriver. In addition to protecting the banks, the submerged riprap will provide habitat for fishes, attached algae, aquatic insects, and mussels. Hydraulics personnel will evaluate the need for bank stabilization at each site.

A field of five dikes will require approximately 300 cu yd (450 tons) of riprap (Table 2). At an estimated cost of $30/ton and allowing $5/ton for spreading, each dike field should cost approximately $15,881. Stabilizing 800 ft of riverbank for a field of five dikes will cost approximately $72,000 (Table 3). This includes 2,200 tons of riprap and 400 tons of washed gravel. The cost of stabilizing the banks is almost five times the cost of a dike field. However, the value of the habitat created by the dike field cannot be maintained without bank stabilization.

Gravel substratum placed adjacent to the dikes will extend at least 300 ft downriver (Figure 1). For a field of five dikes, a total of 900 ft of gravel will be placed. This will include 600 ft adjacent to the dike field and an additional 300 ft downriver of the last dike. Artificially placed substratum will not be a feature of all planned dike fields. Some of the dikes will be placed on the natural clay or sand/silt without modification or augmentation of existing substratum. This will provide a test of the value of added substratum for the freshwater mussels.

Low-water weirs

A weir is an obstruction or dam that partially impounds or diverts flow (Figure 3). Weirs constructed of riprap and placed in the lower third of the water column create a rolling turbulence that should start immediately downriver of the structure. The magnitude of turbulence is directly related

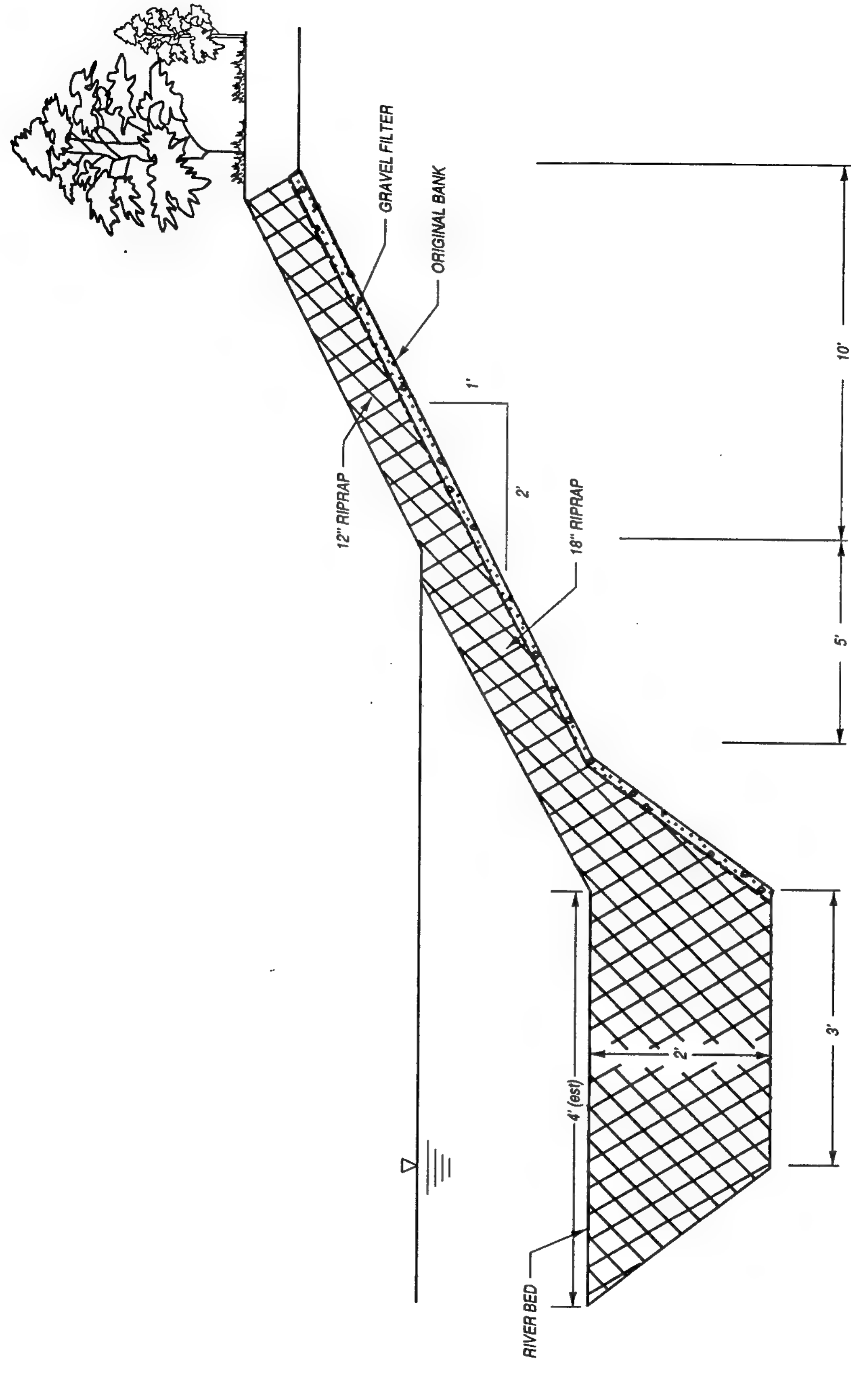

Figure 2. Bank protection required for dike fields

Table 2
Estimated Costs for Dike Fields

Dimensions	Feet
Length	100
Top width	3
Base width	8
Height	3
Cubic feet	1,650
Total dikes in field	5
Total Materials	
Cubic feet	8,250
Cubic yards	306
Total tons	454
Cost/Ton	
Delivered	$30
Spreading	$5
Total	$35
Total cost	$15,881

Note: Cost for three dikes in field: $9,529.

Table 3
Estimated Costs and Quantities of Materials Required for Bank Stabilization

Dimensions	Feet
Riprap	
Length	800
Width	50
Thickness	1
Gravel	
Length	800
Width	50
Thickness	0.2
Cubic feet	8,000
Cubic yards	296
Tons	400

(Continued)

Note: The 800-ft-long bank stabilization is required for five dikes. Bank stabilization for three dikes would require 500 ft of riprap and cost $47,250.

Table 3 (Concluded)	
Cost/Ton (Delivered to site)	
Riprap	$30
Washed gravel	$15
Total Cost	
Riprap	$66,000
Gravel	$6,000
Grand total	$72,000

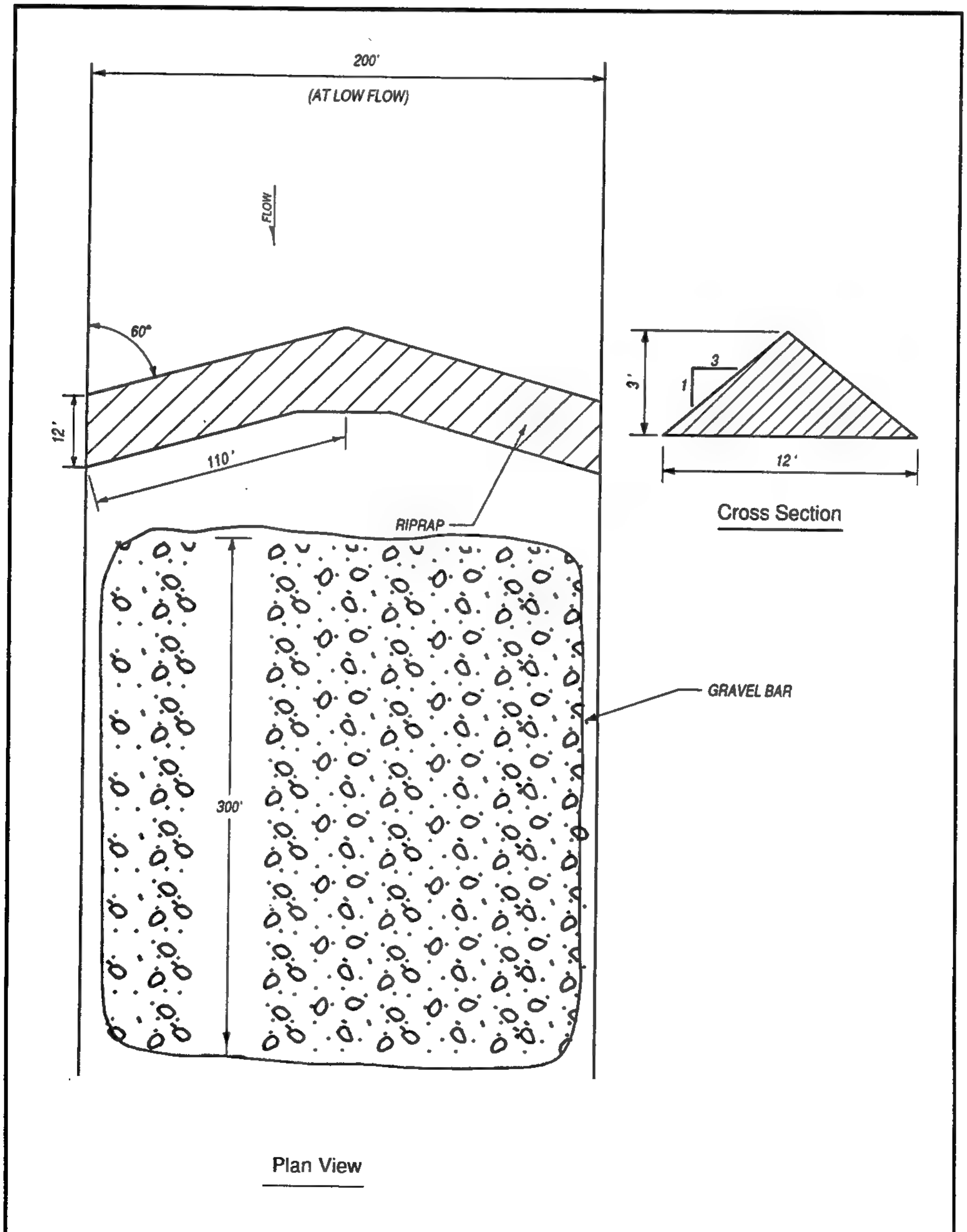

Figure 3. Low-water weir

to the height and width of the weir and will decrease in direct proportion to flow. Therefore, the extent of substrate placement downstream of the structure depends on the distance required to dissipate the kinetic hydraulic energy generated at the weir.

The rolling turbulence should remove recently deposited sediments from the artificially placed substratum. Some sediment deposition will probably occur during low flow; however, sediments should be removed during high flow since rate of bed-load movement is directly proportional to flow velocity.

Weirs are one of the least expensive habitat rehabilitation measures planned for the Big Sunflower River (Table 4). Each weir will require approximately 180 tons of riprap for a total cost of $6,353. Some weirs will have a 300- by 200-ft gravel bar placed immediately downriver (Figure 3). This will provide habitat for mussels and aquatic insects and spawning sites for fishes.

Table 4
Estimated Costs and Quantity of Materials Required for Weirs

Dimensions	Feet
Length	200
Top width	3
Bottom width	8
Height	3
Conversions	
Cubic feet	3,300
Cubic yards	122
Total tons	182
Cost/Ton	
Delivered	$30
Spreading	$5
Total	$35
Total Cost	
Riprap	$6,353
Grand total	$6,353

Substratum Improvement

Gravel will be used to increase the value of selected habitat features. All gravel bars will be approximately 1 ft thick and of various lengths and widths, depending on where they will be placed. Under natural conditions,

mussels can be found in gravel only a few inches thick. However, planning for a thickness of 12 in. will allow for some operator error when gravel is spread. A 900- by 100-ft bar will be used in conjunction with a five-dike field and should cost approximately $67,500 (Table 5). A bar measuring 300 ft long by 200 ft wide (to completely cover the channel downriver of the weir), Figure 3, will cost approximately $45,000. Funding requirements would be reduced if gravel is placed only along the banks, which are more valuable for mussels than the thalweg.

Table 5
Estimated Costs for Substratum Enhancement Using Gravel for a 900-ft-Long by 100-ft-Wide Bar

Dimensions	Feet
Length	900
Width	100
Thickness	1
Conversions	
Total cubic feet	90,000
Total cubic yards	3,333
Total tons	4,500
Cost/Ton	
Delivered	$10
Spreading	$5
Total	$15
Total cost	$67,500

Note: The cost of a gravel bar measuring 300 by 100 ft (for a weir) would be $45,000. The cost of a gravel bar measuring 500 by 100 ft (to augment an existing bar) would be $37,500.

Gravel will also be placed at certain areas to augment or add to existing substratum. Gravel required to cover an area 500 ft long by 100 ft wide (to augment an existing bar) would cost approximately $37,500 (Table 5).

Fish attractors

The Sunflower River suffers from a relative shortage of large, woody structures such as snags that are usually found in rivers in the southeastern United States. These structures are crucial in the function of riverine biotic communities. Although typically referred to as fish attractors, these devices benefit many other aquatic organisms. Benke et al. (1985) have shown that in the Satilla River, Georgia, invertebrate diversity, biomass, and production were considerably higher on the surfaces of snags than in muddy or sandy substratum. In the Satilla River, 78 percent of the

invertebrate biomass in drift originated from snags, and half of the major fish species obtained at least 60 percent of their prey biomass from snag habitats (Benke et al. 1985). All common riverine fishes feed on invertebrates from snags to some extent.

One type of fish attractor could be made from trees, logs, or woody debris. These should be anchored so that crowns are oriented downstream. Each tree, log, or unit of woody debris should be anchored to the bank with cables and should also include a streambed anchor. (The cable selected for use should be of a type that would last a long time underwater.) The woody material should be placed at depths in which it will be permanently submerged, since repeated drying and wetting results in rapid decomposition of woody material. Permanent submergence will therefore prolong the life of the structure and allow the snag habitats to operate over a longer duration. The approximate cost of materials necessary to anchor each tree or log would be $114. Total cost, which includes labor, transportation to the site, and placement in the river, is estimated at $500.

Attractors could also be constructed of stacked, perforated, 10-ft lengths of 4-in.-diam polyvinyl chloride (PVC) (Figure 4). A variety of attractors are available, and several types could be used to increase habitat diversity. PVC pipe can be used for construction since it will not decompose and is inexpensive. The attractors should be permanently submerged to prevent damage to boats and boat engines and to preclude vandalism. The approximate cost of materials for a single PVC structure would be $90. Total cost, which includes labor, transportation to the site, and placement in the river, is estimated at $500.

Within hours of placement, a coating of bacteria will begin to develop on the surfaces of the structures (Horne and Goldman 1994). Bacteria have been shown to be a major component in the diet of snag-dwelling mayfly nymphs (Benke et al. 1992), an important macroinvertebrate group in the diet of many fishes. Within days, algae will attach and algal succession will begin. The algae provides additional food for invertebrates, many of which will be carried to the structures via drift. A number of fish species will be attracted to the structures and will also use the colonizing invertebrates as a food source.

Both the woody and the PVC structures can be placed anywhere they are desired within the Sunflower River. It is anticipated that they will be placed on gravel substratum in association with dikes and weirs. In addition, the attractors can be placed at existing beds to encourage additional fish to use the area.

Vegetation for bank protection

In addition to riprap, vegetation will prevent bank erosion. Roots hold soils in place, and plants remove water from the soil, increasing its cohesiveness and reducing erosion. Three species of trees were selected for

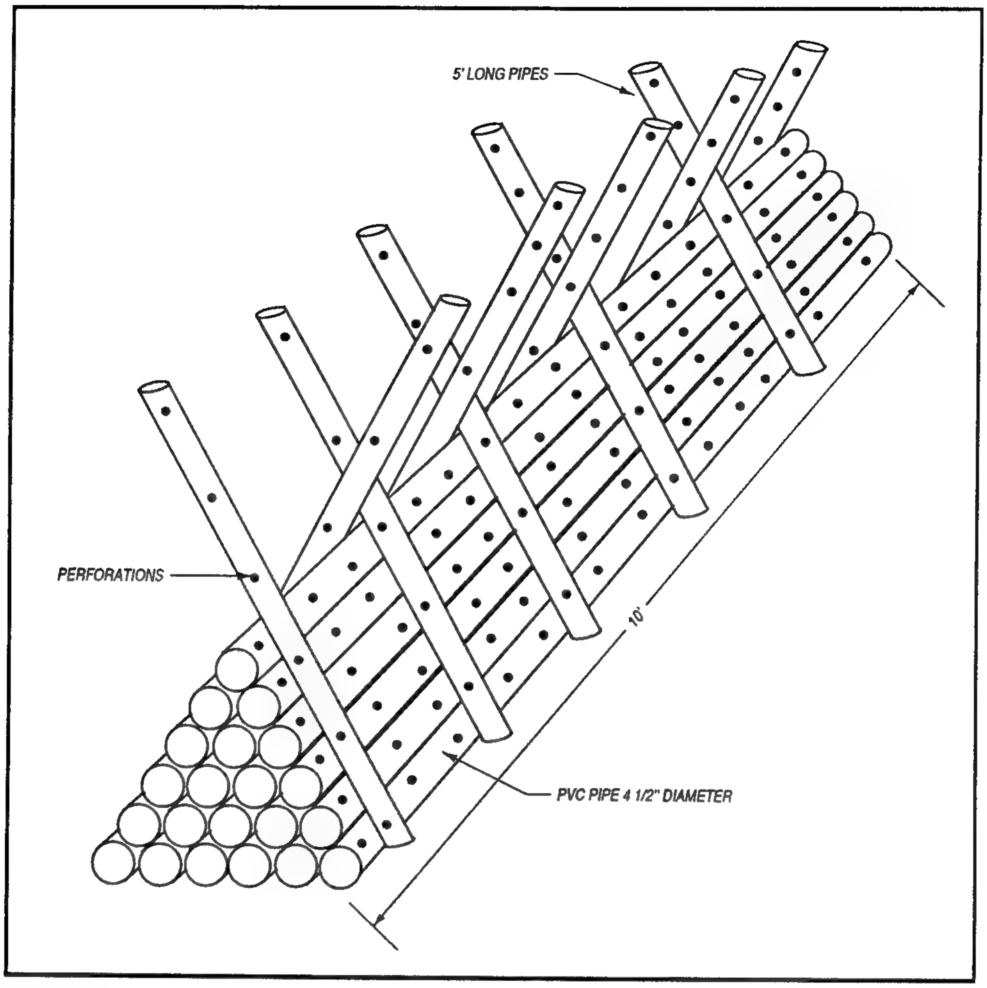

Figure 4. Fish attractor

revegetation, based on how densely they could be planted and their ability to tolerate existing conditions along the Big Sunflower River. These are green ash (*Fraxinus pennsylvanica*), bald cypress (*Taxodium distichum*), and Nuttall oak (*Quercus nuttallii*).

An estimate of costs required to revegetate an 800 by 50 ft strip of land along the Big Sunflower River is $2,111 (Table 6). This assumes that all plants are placed on a 6-ft center and there is some loss because of mortality.

Additional Measures to Reduce Impacts to Mussels of the Big Sunflower River

In addition to the habitat improvement structures, the existing dredging plan will be modified to protect as much mussel habitat as possible. This includes a no-work area at the high-density bed immediately downriver of abandoned Lock and Dam 1 (RM 53.9 to 54.1) and upriver of the Holly

Table 6
Estimated Costs to Revegetate Riverbanks

Species	**Cost/Plant**
Green ash	$0.55
Bald cypress	$0.55
Nuttall oak	$0.55
Planting center, ft	6.00
Area to Vegetate	**Feet**
Length	800
Width	50
Total, square feet	40,000
Summary	
Plants required	1,111
Total cost of plants	$611
Total site preparation	$1,000
Total labor to plant	$500
Total costs	$2,111

Note: The total area to vegetate shoreline adjacent to five dikes would be 800 ft. A total of 500 ft would be used to vegetate an area for three dikes, which would cost $1,882.

Bluff Cutoff (RM 26.4 to 26.6). In addition, there will be three designated avoidance areas where dredging will be restricted to minimize impacts to the mussel resource. Avoidance areas will be located immediately downriver of Bay Lake Run on the right descending bank (RDB) (RM 71.6), upriver of abandoned Lock and Dam 1 on the left descending bank (LDB) (RM 53.9 to 54.1), and the upper 1 mile, LDB, of the channel excluded by the Holly Bluff Cutoff.

The highest mussel concentrations in the Big Sunflower River are in the depositional zones along both banks. Therefore, the dredge cut will be located in the center of the channel to avoid mussels. In addition, the cut will be as narrow and as deep (into the substratum) as possible.

3 Placement of Proposed Habitat Features

Background

The Team developed five plans that should improve habitat for mussels and other aquatic organisms in the Big Sunflower River. Recommended improvement features in the plans are as follows:

a. Straight dike fields with either three or five dikes. Some fields will have coarse-grained sediments (probably 1- to 3-in.-diam gravel) placed adjacent to them for at least 300 ft downriver. All dike fields will require bank stabilization.

b. Weirs placed from bank to bank. At some weirs, a 300-ft-long by 200-ft-wide gravel bar will be placed immediately downriver.

c. Aquatic biota (fish) attractors. Attractors will be placed at selected sites associated with other habitat features. These will attract aquatic invertebrates and fishes, which are hosts for mussels.

d. Revegetation. If necessary, riverbanks will be revegetated with flood tolerant plants.

e. Substratum improvement. Since the majority of the sediments in the Big Sunflower River consists of mud and sand, coarse-grained sediments will be used to augment existing beds, thereby providing additional habitat for mussels. The Team recommended that some reaches without any coarse substratum be improved with gravel.

Description of Habitat Features in Each River Reach

The following is a list of habitat features proposed for each of five reaches of the Big Sunflower River. The following forms the basis for Plan 1 developed by the Team. The remaining four plans developed by the Team are modifications of the original list.

Reach 1 - Upriver of Lock and Dam 1 to RM 75.6

Description. Reach 1 of the Big Sunflower River extends from abandoned Lock and Dam 1 (RM 54.6) upriver to RM 75.6 (Figure 5). This river reach differs morphologically from that downriver of Lock and Dam 1 by being more shallow and narrow. Substratum is predominantly fine sands and silts, which can be several feet deep along the shore. No distinctive, high-density mussel beds were found in this section of the river (Miller and Payne, in preparation). Mussels are scattered with mean densities of approximately 5.5/sq m. The majority of mussels were located on the LDB and RDB with comparatively few in midchannel.

Proposed habitat improvements. The morphology of this reach is conducive to placement of physical structures that modify water velocity. Six areas in Reach 1 were identified as suitable for some type of improvement (Appendix A). The areas suitable for improvements are depicted in Figure 5 and listed below:

RM 75.6; Site 1-1. This site is located in a straight reach in the upper section of the project area. This area would be suitable for dikes, weirs, and associated gravel and fish attractors.

RM 71.6; Site 1-2. This site is located immediately downriver of the confluence of Bay Lake Run. Moderately high-density populations of mussels were found along the RDB (Miller and Payne, in preparation). This location was identified as an avoidance area to protect mussels, and dredging will be restricted to LDB. After dredging, this area will be improved with placement of fish attractors.

RM 68.6; Site 1-3. This location is in a straight reach and is similar to Site 1-2. This area would be suitable for dikes, weirs, and associated gravel and fish attractors.

RM 66.6; Site 1-4. The area is similar to that at RM 75.6, and it is suitable for dikes and weirs. No gravel or fish attractors will be placed at this location. This will provide an opportunity to test the ability of these features to provide habitat for freshwater mussels and other aquatic biota.

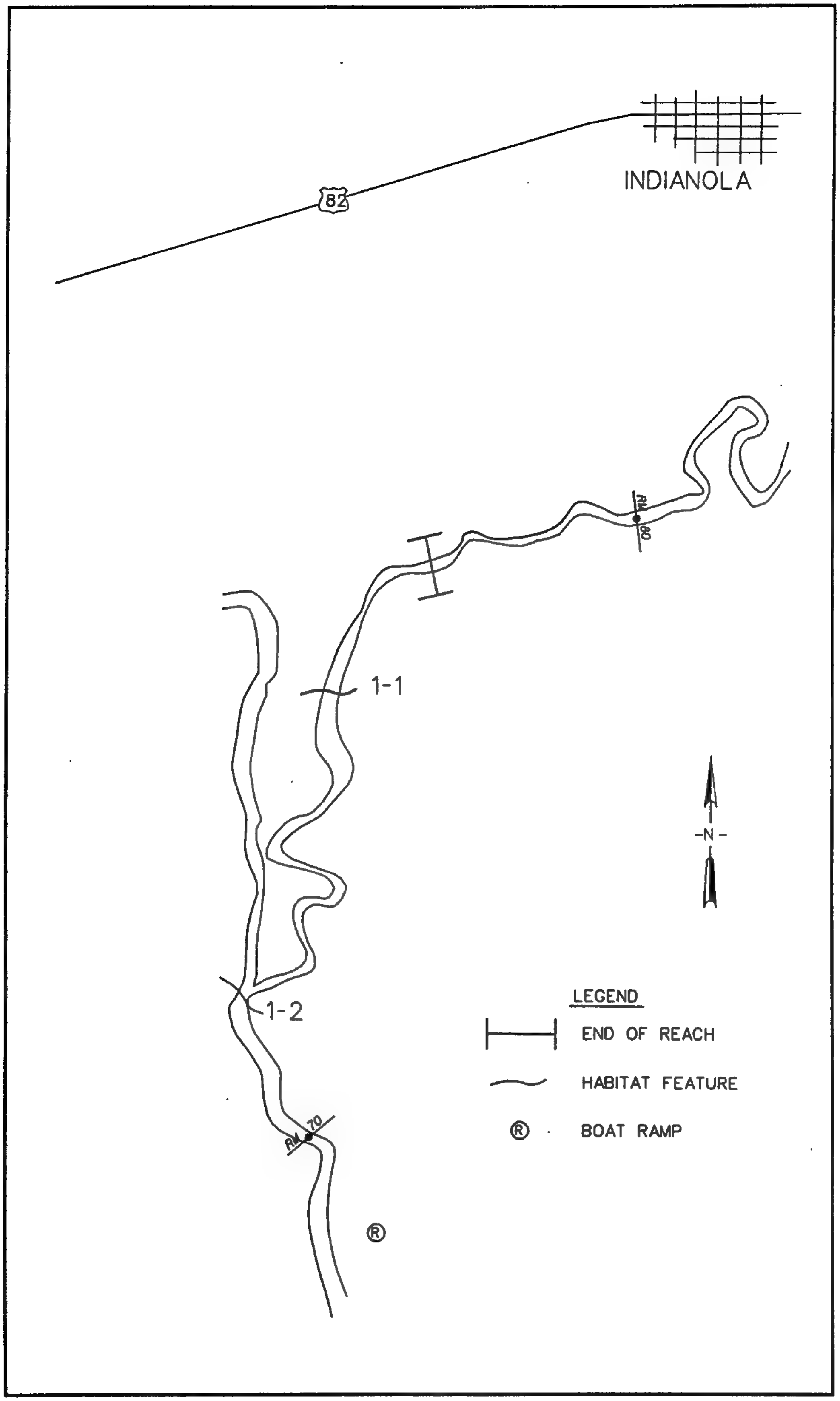

Figure 5. Upper and lower sections of Reach 1 of the Big Sunflower River Habitat Improvement Project (Continued)

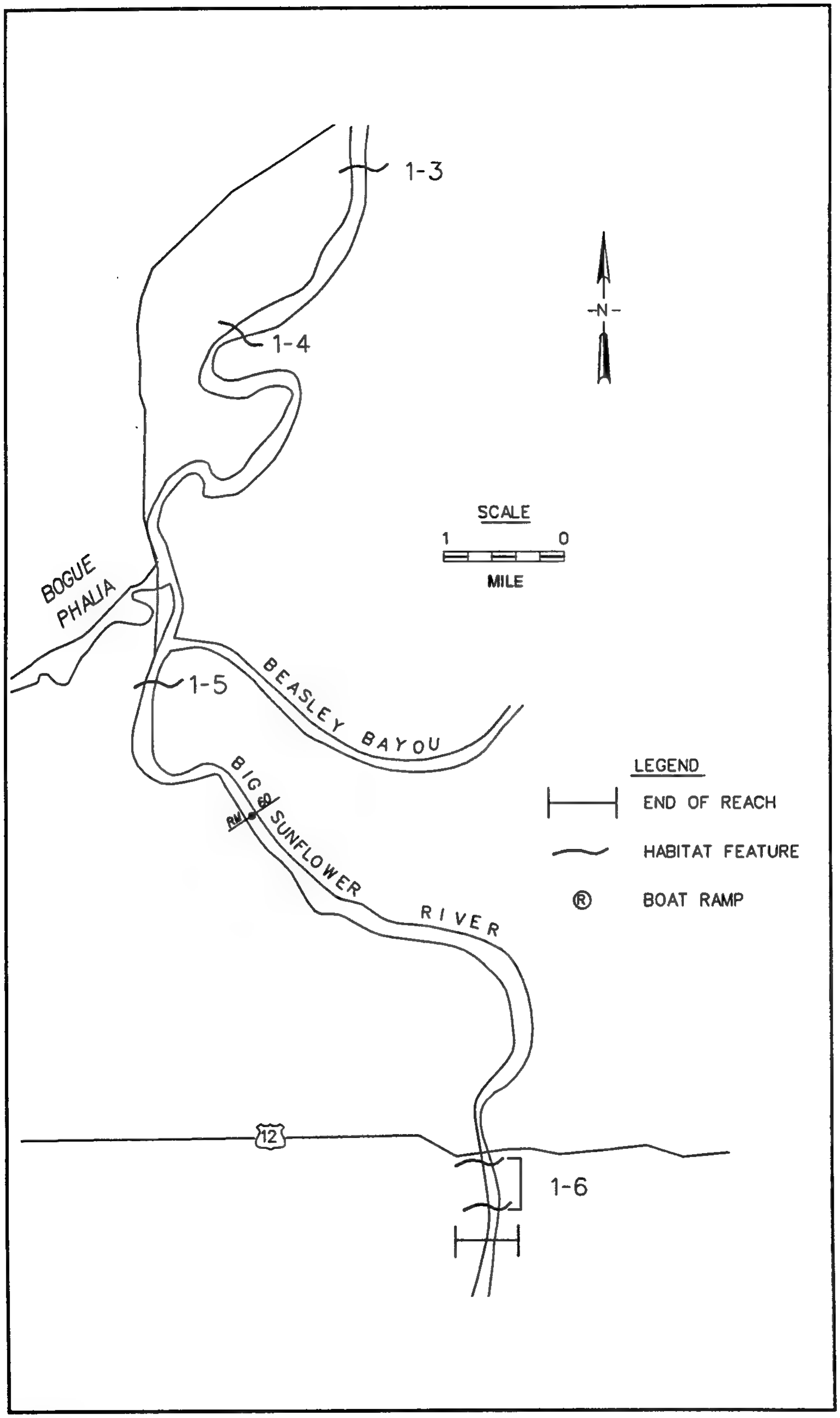

Figure 5. (Concluded)

RM 61.6; Site 1-5. Site 1-5 will have the same features as planned for Site 1-4 except that it will also include fish attractors.

RM 56.1; Site 1-6. There is a moderately dense assemblage of mussels immediately upriver of abandoned Lock and Dam 1 along the LDB at this location. This will be another avoidance area to protect as many mussels as possible. Fish attractors will be deployed at this site.

Reach 2 - Between Lock and Dam 1 and the Holly Bluff Cutoff

Description. Reach 2 extends from Lock and Dam 1 downriver to the upper end of the Holly Bluff Cutoff at RM 18.7, a distance of approximately 36 river miles (Figure 6). A localized, high density mussel bed (mean density equal to 235 individuals/square meter) is located immediately downriver of abandoned Lock and Dam 1. The bed covers an area approximately 300 ft long and 150 ft wide. Substratum at the bed consists of sand and gravel; additional sand and gravel will be used to increase the downriver extent of this bed. This will be a no-work zone.

Low to moderately high-density mussel assemblages are also found immediately upriver of the Holly Bluff Cutoff at RM 27.3 to 27.8.

Proposed habitat improvements. This river reach, like Reach 1, is conducive to placement of physical structures that modify water velocity. Two areas were considered suitable for habitat improvements. Habitat improvement features for Reach 2 are listed in Appendix A, their locations depicted in Figure 6, and are summarized below:

RM 54.6 (Existing Bed); Site 2-1. The downriver extent of this bed will be increased by adding gravel. In addition, fish attractors will be deployed. Riprap will be used to help stabilize the upper end of the dredge cut, immediately downriver of the mussel bed.

RM 41.6-44.6; Sites 2-2 and 2-3. This relatively straight reach has scattered mussels located along the RDB and LDB. This area is suitable for dike fields and weirs.

RM 44.6-48.6; Sites 2-4 and 2-5. This area is similar to Sites 2-2 and 2-3. Dike fields, weirs, added substratum, and fish attractors are suitable for this reach.

RM 27.8 (Existing Bed); Site 2-6. A moderately high-density bed is located upriver of the Holly Bluff Cutoff. Gravel will be added to the existing bed, and attractors will be used to provide habitat for fish and other aquatic organisms.

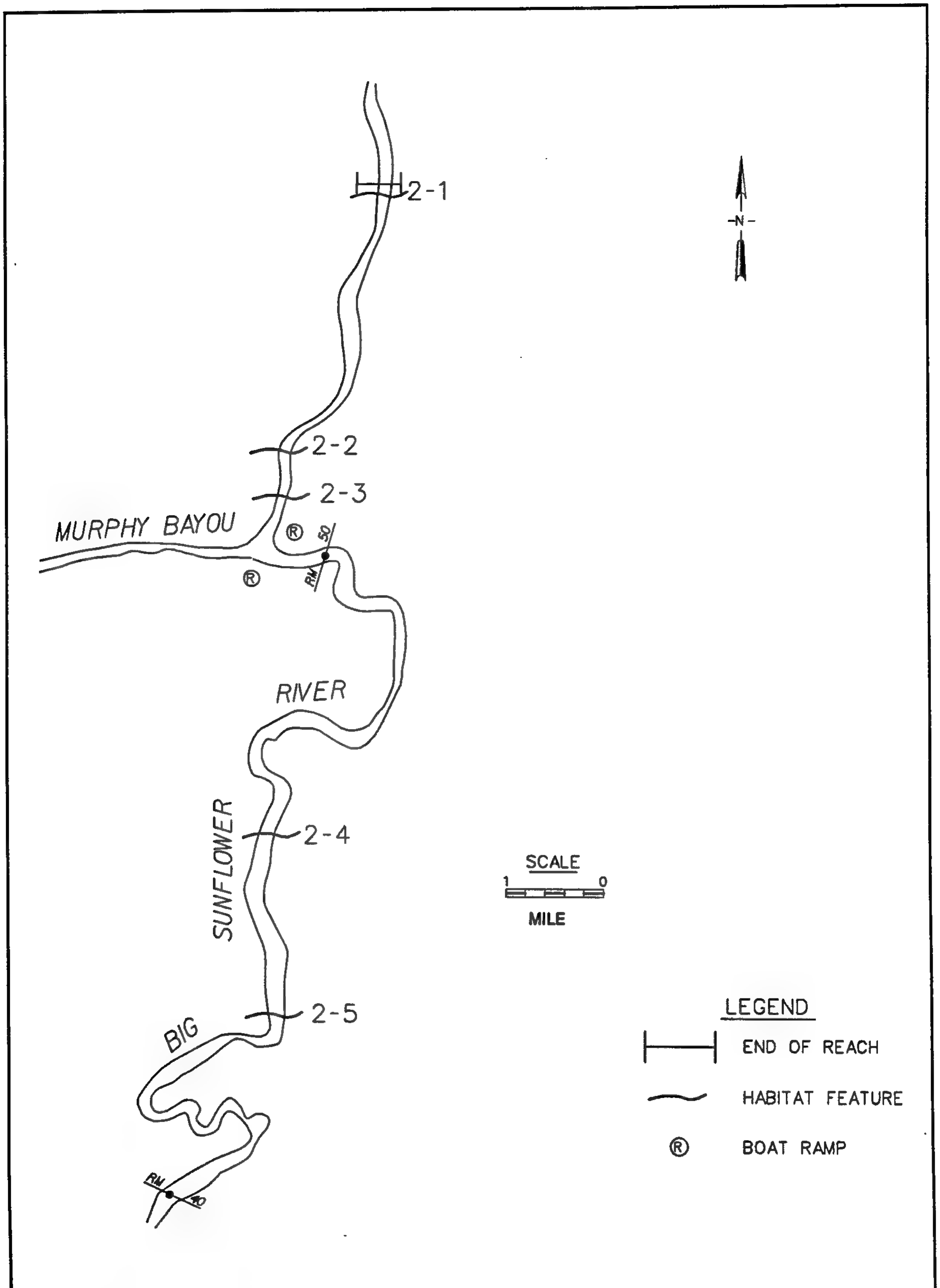

Figure 6. **Upper and lower sections of Reach 2 of the Big Sunflower River Habitat Improvement Project (Continued)**

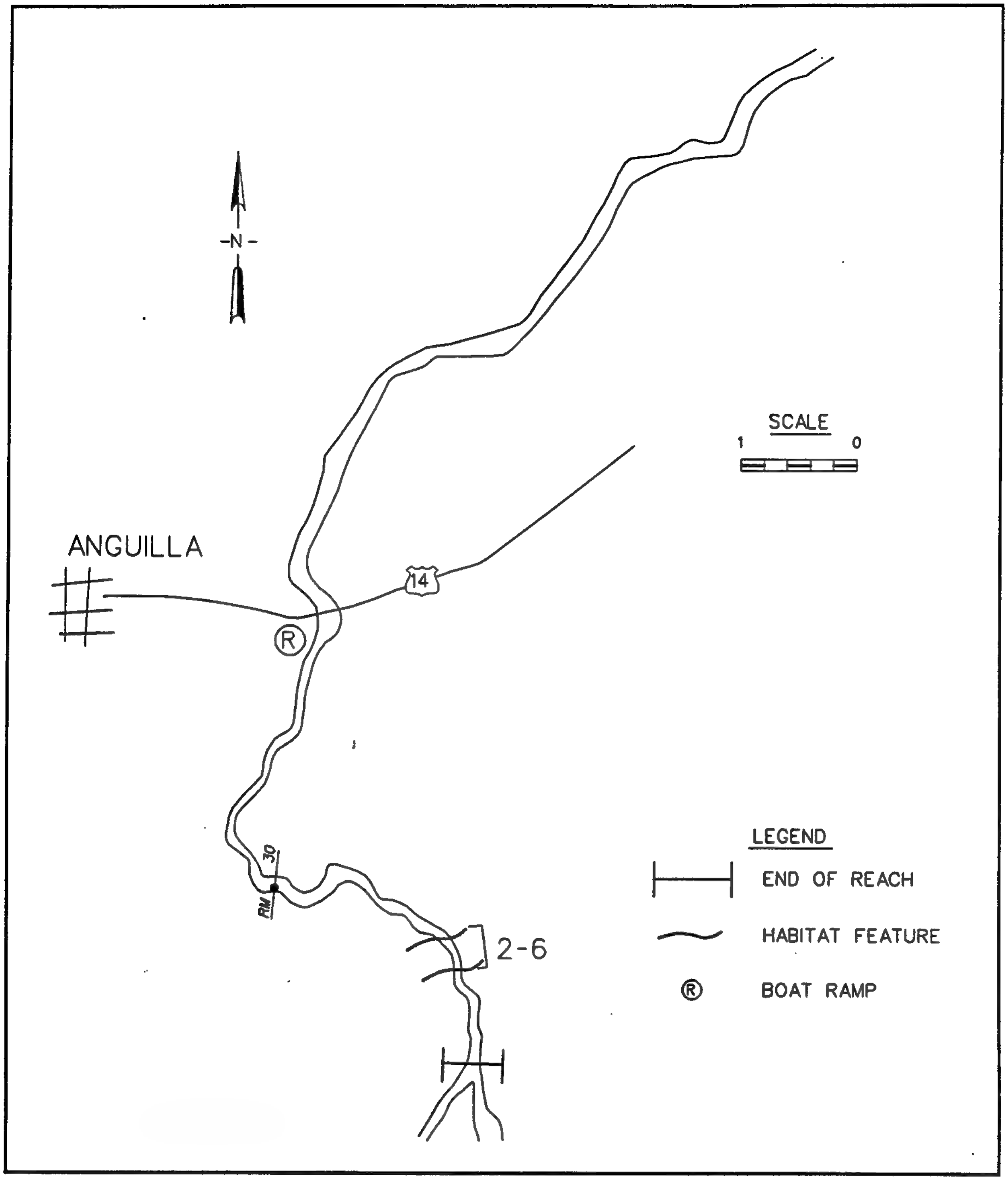

Figure 6. (Concluded)

Reach 3 - Holly Bluff Cutoff

Description. The Holly Bluff Cutoff is a 7.4-mile-long straight channel that connects two portions of the Big Sunflower River (Figure 7). Less than 1,000 ft from its downriver end, there is a weir that helps maintain flow in the excluded channel. Substratum in the Holly Bluff Cutoff consists of sand and clay in the channel and silt, sand, and clay along the

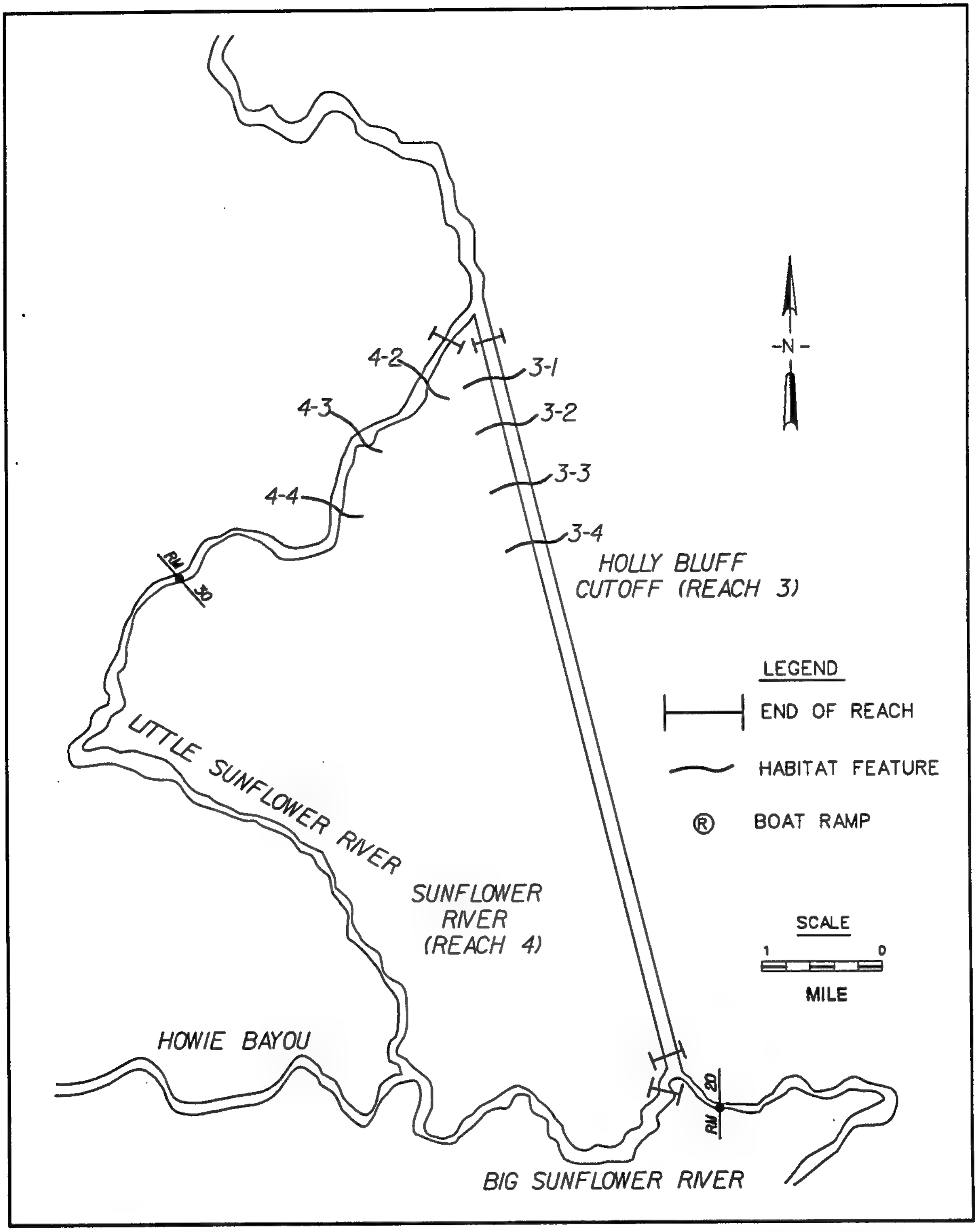

Figure 7. Reaches 3 and 4 of the Big Sunflower River Habitat Improvement Project

banks. Banks are steep and poorly vegetated. Scattered, low-density populations exist upriver of the weir (less than 1.0/m). Mussels probably were carried in by high water from the bed located upriver of the cutoff. Low-density, discrete zones of mussels were found between the weir and

the point where the cutoff rejoins the Big Sunflower River. Mussels were restricted to the RDB and LDB and were not found in midchannel.

Proposed habitat improvements. This reach lacks suitable substratum as well as instream cover for fishes and other aquatic organisms. Because of the hydraulic design of the cutoff, it is not possible to alter flow with dikes or weirs. Habitat improvement measures will consist of placing gravel substratum and fish attractors and revegetating banks (Appendix A). There will be no need to stabilize banks since dikes will not be used. Improvement sites are depicted on Figure 7.

Distance from start of Cutoff = 0.5 miles; Site 3-1. A 500- by 100-ft gravel bar will be placed along one bank. A 500-ft length of bank will be revegetated, and four fish attractors will be placed on gravel.

Distance from start of Cutoff = 1.0 miles; Site 3-2. This section will have the same features listed for Site 3-1.

Distance from start of Cutoff = 1.5 miles; Site 3-3. Habitat features will consist of a gravel bar and bank revegetation.

Distance from start of Cutoff = 2.0 miles; Site 3-4. Features at this site will be the same as those listed for Site 3-3.

Reach 4 - Bendway partially excluded by Holly Bluff Cutoff

Description. This reach includes approximately 15 river miles excluded by the Holly Bluff Cutoff (Figure 7). In this reach, banks are stable and well vegetated with trees and shrubs. Water velocity is moderate to high in the upper section where there are moderately dense mussel beds. Substratum in areas with mussels consists of mud, detritus, and shells. River mile designations in this reach are "unimproved" (the same as on topographic maps and not affected by presence of the Holly Bluff Cutoff).

Habitat improvements. This reach is not suitable for dikes and weirs. Habitat improvement methods will be limited to placement of substratum and fish attractors (see Appendix A). The following are proposed:

RM 34.5; Site 4-1. The existing bar will be extended by adding a 500- by 100-ft section of gravel. Four fish attractors will be placed on the newly extended gravel bar. The first mile of this reach, along the LDB, has been designated as an avoidance area to protect existing mussels.

RM 34.0; Site 4-2. This site will be improved with fish attractors and no additional gravel. This will enable a test of the ability of added gravel to improve habitat with and without attractors.

RM 33.0; Site 4-3. Habitat improvement features at this reach will be the same as those for Site 4-1.

RM 32.0; Site 4-4. Habitat improvement features at this reach will be the same as those at Site 4-2.

Reach 5 - Downriver of Holly Bluff Cutoff, RM 20.2 to RM 6

This reach includes approximately 16 miles of the most downriver section of the maintenance project (Figure 8). Low densities of mussels are found along the shore although no mussel beds were found. No improvement features would be considered for this river reach for Plans 1 through 4. However, improvements are suggested in this reach in Plan 5 (to be discussed in Chapter 4).

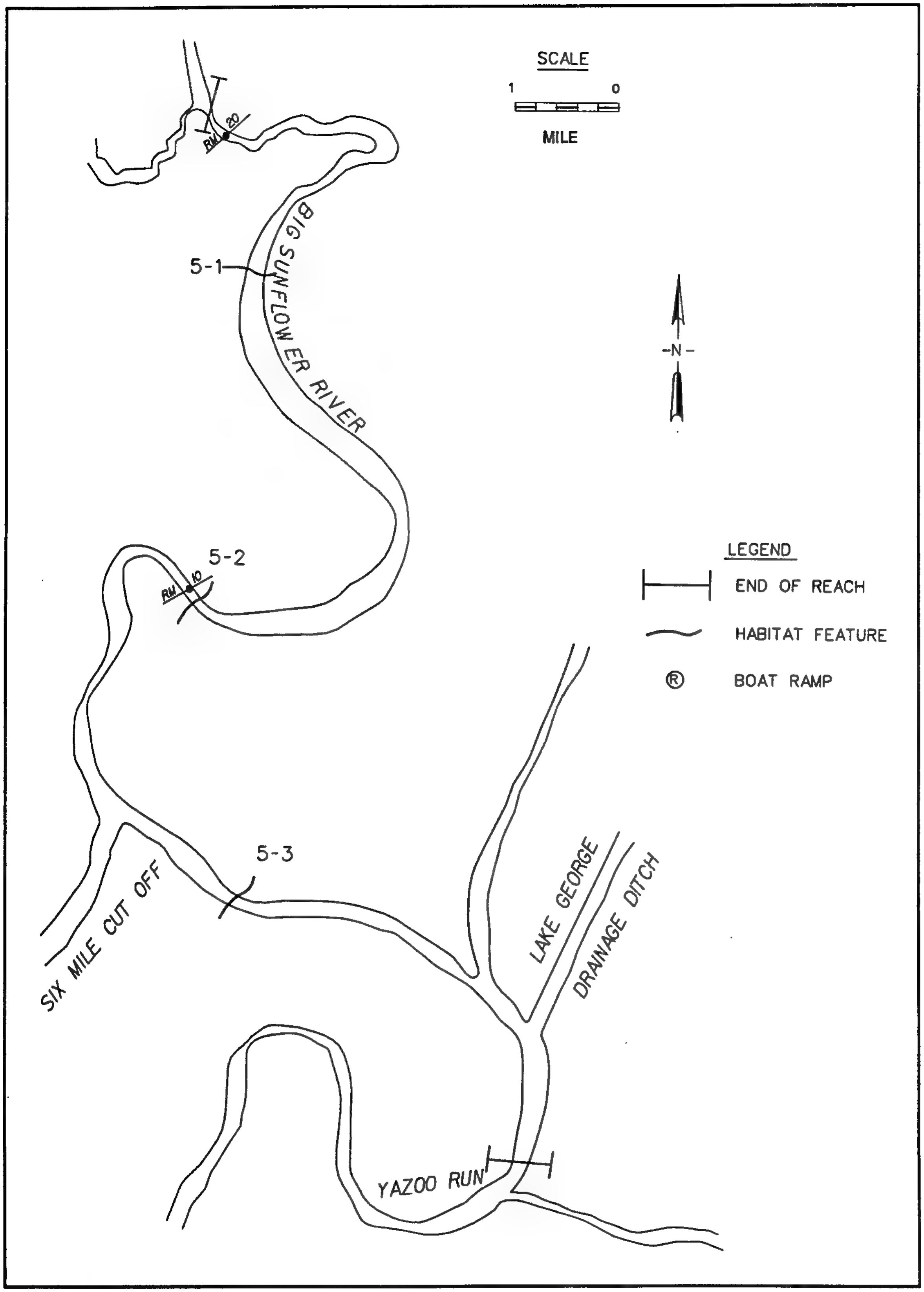

Figure 8. Reach 5 of the Big Sunflower River Habitat Improvement Project. (This figure depicts habitat improvements specific to Plan 5 only)

4 Discussion of the Five Recommended Habitat Improvement Plans

Background

The Habitat Improvement Team spent considerable time developing a basic plan for the Big Sunflower River to mitigate for losses because of proposed maintenance. After the Team developed this plan, they prepared four alternatives (Numbers 2-5). These plans differ from the basic plan in that they are less expensive and contain fewer improvement features. Complete documentation of each plan is in Appendixes A-E. The cost of each habitat feature, applicable to all plans, appears in Table 7. The cost of all features by reach is listed in Table 8, and the number of features in each reach is in Table 9. The total cost of each plan is summarized in Table 10, and the total area of aquatic habitat (in square feet) for each plan is in Table 11.

Table 7
Estimated Unit Costs for Each Mitigation Feature for All Recommended Plans

Item	Cost
Dike field (5 dikes)	$15,881
Weir	$6,353
Attractor	$500
Bank stabilization (800 ft)	$72,000
Revegetation (800 by 50 ft)	$2,111
Revegetation (500 by 50 ft)	$1,882
Substratum improvement	
Gravel (900 ft for dike field)	$67,500
Gravel (300 ft for weir)	$45,000
Gravel (500 ft add to existing bar)	$37,500
Gravel (200 by 25 ft for Holly Bluff Cutoff)	$3,750

Table 8
Summary of Estimated Costs, by River Reach, for Five Recommended Plans for the Habitat Rehabilitation Project for the Big Sunflower River, Mississippi

River Reach	Plan 1		Plan 2		Plan 3	
	Cost	Percent	Cost	Percent	Cost	Percent
1	$626,380	46.95	$498,746	43.57	$311,079	51.60
2	$392,190	29.40	$330,484	28.87	$291,845	48.40
3	$161,528	12.11	$161,528	14.11	$0	0.00
4	$154,000	11.54	$154,000	13.45	$0	0.00
5	$0	0.00	$0	0.00	$0	0.00
Total	$1,334,098	100.00	$1,144,758	100.00	$602,924	100.00

River Reach	Plan 4		Plan 5	
	Cost	Percent	Cost	Percent
1	$626,380	61.50	$211,558	84.69
2	$392,190	38.50	$4,000	1.60
3	$0	0.00	$29,250	11.71
4	$0	0.00	$2,000	0.80
5	$0	0.00	$3,000	1.20
Total	$1,018,570	100.00	$249,808	100.00

Table 9
Summary of Habitat Rehabilitation Features for Each of Five Recommended Plans for the Big Sunflower River Habitat Improvement Project

Habitat Feature	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Dike Fields					
(5 Dikes)	6	6	3	6	0
(3 Dikes)	0	0	0	0	2
Weirs	6	0	3	6	0
Attractors	72	48	32	56	54
Bank Stabilization					
(800 ft for 5 dikes)	6	6	3	6	0
(500 ft for 3 dikes)	0	0	0	0	2
Revegetation	10	8	2	6	0
Substratum Improvement					
(900 ft for 5 dikes)	3	3	2	3	0
(600 ft for 3 dikes)	0	0	0	0	2
(500 ft add to existing bar)	10	10	2	2	0
(300 ft for weir)	3	0	2	3	0
(200 ft strip for HBC)	0	0	0	0	5
Total features	116	81	49	88	65

Note: HBC = Holly Bluff Cutoff.

Table 10
A Comparison of Funds Required for Each Habitat Feature of the Five Recommended Plans for the Big Sunflower River Habitat Improvement Project

Habitat Feature	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Funds Required					
Dike Fields	$95,286	$95,286	$47,643	$95,286	$19,058
Weirs	$38,118	$0	$19,059	$38,118	$0
Attractors	$36,000	$24,000	$16,000	$28,000	$27,500
Bank Stabilization	$432,000	$432,000	$216,000	$432,000	$94,500
Revegetation	$20,194	$15,972	$4,222	$12,666	$0
Substratum Improvement	$712,500	$577,500	$300,000	$412,500	$108,750
Grand Total	$1,334,098	$1,144,758	$602,924	$1,018,570	$249,808
Percentage of Total					
Dike Fields	7.14	8.32	7.90	9.35	7.63
Weirs	2.86	0.00	3.16	3.74	0.00
Attractors	2.70	2.10	2.65	2.75	11.01
Bank Stabilization	32.38	37.74	35.83	42.41	37.83
Revegetation	1.51	1.40	0.70	1.24	0.00
Substratum Improvement	53.41	50.45	49.76	40.50	43.53
Grand Total	$1,334,098	$1,144,758	$602,924	$1,018,570	$249,808

Table 11
Summary of Total Area Improved for Recommended Plans for the Big Sunflower River Habitat Improvement Project

Habitat Feature	Length ft	Width ft	Plan 1		Plan 2		Plan 3		Plan 4		Plan 5	
			Total Number	Affect sq ft	Total Number	Affect sq ft	Total Number	Affect sq ft	Total Number	Affect sq ft	Total Number	Affect sq ft
Dike Fields												
(5 Dikes)	900	100	6	540,000	6	540,000	3	270,000	6	540,000	0	0
(3 Dikes)	600	100	0	0	0	0	0	0	0	0	2	120,000
Weirs	300	200	6	360,000	0	0	3	180,000	6	360,000	0	0
Bank Stabilization												
(800 ft for 5 dikes)	800	50	6	240,000	6	240,000	3	120,000	6	240,000	0	0
(500 ft for 3 dikes)	500	50	0	0	0	0	0	0	0	0	2	50,000
Revegetation	800	50	10	400,000	8	320,000	2	80,000	6	240,000	0	0
Substratum Improvement												
(900 ft for 5 dikes)	900	100	3	270,000	3	270,000	2	180,000	3	270,000	0	0
(600 ft for 3 dikes)	600	100	0	0	0	0	0	0	0	0	2	120,000
(500 ft add to existing bar)	500	100	10	500,000	10	500,000	2	100,000	2	100,000	0	0
(300 ft for weir)	300	200	3	180,000	0	0	2	120,000	3	180,000	0	0
(200 ft strips for HBC)	200	25	0	0	0	0	0	0	0	0	5	25,000
Total area, sq ft				2,490,000		1,870,000		1,050,000		1,930,000		315,000
Total features[1]			44		33		17		32		11	

[1] Does not include fish attractors.

Description of Habitat Improvement Plans

Plan 1

Plan 1 is the basic habitat rehabilitation plan developed by the Team (See Appendix A). It was prepared without concern for costs; the intent was to develop a plan that included a variety of features. Location of the various structures, such as dikes and weirs, was based upon information on substratum type, channel configuration, and water depth.

Plan 1 costs approximately $1.3 million and is the most expensive of the five plans. The majority of funds will be used in Reaches 1 (47 percent) and 2 (29 percent) that already have valuable mussel assemblages. More than 50 percent of the funds are used for substratum improvement and approximately 32 percent are used for bank stabilization associated with construction of dike fields.

This plan will provide an opportunity to test habitat improvement features. The plan includes six dike fields, four in Reach 1 and two in Reach 2. Gravel substratum will be included with two fields in Reach 1 and one field in Reach 2. This will enable a test of the value of substratum for mussels when altering hydrologic regimen. In addition, the success of dike fields in two different river reaches can be tested with replication.

Six weirs will be constructed, four in Reach 1 and two in the second reach. Two weirs in Reach 1 and one weir in Reach 2 will be constructed without placement of additional substratum. The effects of weirs in two river reaches with and without substratum can be tested.

Seventy-two fish attractors will be deployed. Attractors will be placed on gravel substratum at selected weirs and dike fields. Not all dike fields and weirs will have fish attractors. This will enable a test of the effectiveness of attractors on mussel recruitment. Attractors will also be placed at sites with moderate to high-density mussel populations. Fish attractors will also be placed at areas where coarse-grained substratum is used to augment an existing bed. An example of this is at RM 54.6 immediately downriver of abandoned Lock and Dam 1.

Bank stabilization with gravel and riprap, an expensive aspect of these habitat features will be required for dike fields but not weirs. Dikes will direct water toward the opposite bank and could cause erosion. Prior to construction, a detailed analysis of each improvement site will be made to determine the need for bank stabilization.

It was estimated that 10 areas associated with habitat features could require revegetation with flood-tolerant trees. Revegetation will protect banks from erosion and reduce the likelihood of locally produced sediments being deposited on artificially placed substratum.

The Team decided that additional plans based on Plan 1 should be prepared. This was done to provide decision makers with options with respect to costs, number, and type of features. The following is a discussion of four additional plans developed by the Team:

Plan 2

Plan 2 is identical to Plan 1 except that all weirs have been removed (Appendix B). This was done because of concern that overall value of the weirs might not be high in comparison with other features. Substratum placement in association with weir construction is also eliminated. The estimated funds required for this plan is $1.1 million, which is about $200,000 less than Plan 1. This plan will enable comparison of dike fields with and without substratum and between Reaches 1 and 2. Features considered for Reaches 3 and 4 are the same in Plans 1 and 2.

If this plan is adopted, there will be no knowledge gained on the possible value of weirs. In addition, the total area of habitat improvements in the Big Sunflower River would be reduced (see Table 11 for a comparison).

Plan 3

In Reach 1 of this plan, there will be only two dikes, two weirs, and two areas of bank stabilization (Appendix C). Habitat features recommended for Reach 2 will also be reduced; there will be only one dike and one weir. No habitat features are planned for Reaches 3 and 4. The intent of this plan is to eliminate habitat improvement features from reaches with comparatively low value for mussels.

The total required funds for Plan 3 will be $602,924, which is less than funds required for Plan 1 (Table 8). This plan will enable a demonstration of the value of dikes and weirs, although there is limited ability to conduct statistical tests on their value since features are not replicated.

Plan 4

Habitat features for Reaches 1 and 2 for this plan are identical to those of Plan 1 (Appendix D, Table 8). The ability to test the success of dikes and weirs in providing suitable habitat for mussels is maintained. However, Plan 4 does not include any habitat features for Reaches 3 and 4. The estimated funds required for this plan is $1.0 million.

Plan 5

The estimated funds required for Plan 5 will be $249,808, which is substantially less than required for the other four plans (Appendix E, Table 8).

This plan contains no weirs and associated substratum improvement. In addition, dike fields will contain only three dikes instead of five and therefore will require less bank protection and gravel substratum. However, the ability of dikes to improve habitat for mussels will be maintained, only the total amount of affected area will be reduced.

Reach 1 will have two three-dike fields with added substratum and bank protection. As with all previous plans, fish attractors will be placed at avoidance areas, such as at RM 71.6. No major habitat features are considered for Reach 2. Fish attractors will be placed at two high-quality mussel beds at RM 54.6 and 27.8.

Habitat features considered for the Holly Bluff Cutoff (Reach 3) differ substantially from recommendations in previous plans (Figure 9). Narrow strips of gravel will be placed along one shore at three locations in the cutoff upriver of the existing weir. These strips of gravel, measuring 200 ft long by 25 ft wide, will be placed at distances of 0.5, 1.5, and 5.0 miles from the upriver end of the cutoff. This design will enable a test of the effects of the ability of the moderately high-density bed immediately upriver to supply adults to these bars. During a survey in 1994, divers found adult mussels in the cutoff that probably were washed in by high water. It is likely that numbers of displaced mussels in the cutoff diminish moving downriver. Subsequent monitoring of these gravel strips will provide an opportunity to test this hypothesis.

Substratum will also be placed downriver of the existing weir, a feature not present in the other plans. Two strips of gravel, each measuring 200 ft long by 25 ft wide, will be placed 200 and 800 ft downriver of the weir. A major goal of this plan is to improve habitat in the Holly Bluff Cutoff, which has low value for mussels.

Fish attractors will be placed at two locations in Reach 4. In addition, attractors (although no additional substratum) will be placed in Reach 5. None of the other plans have habitat improvements for this reach.

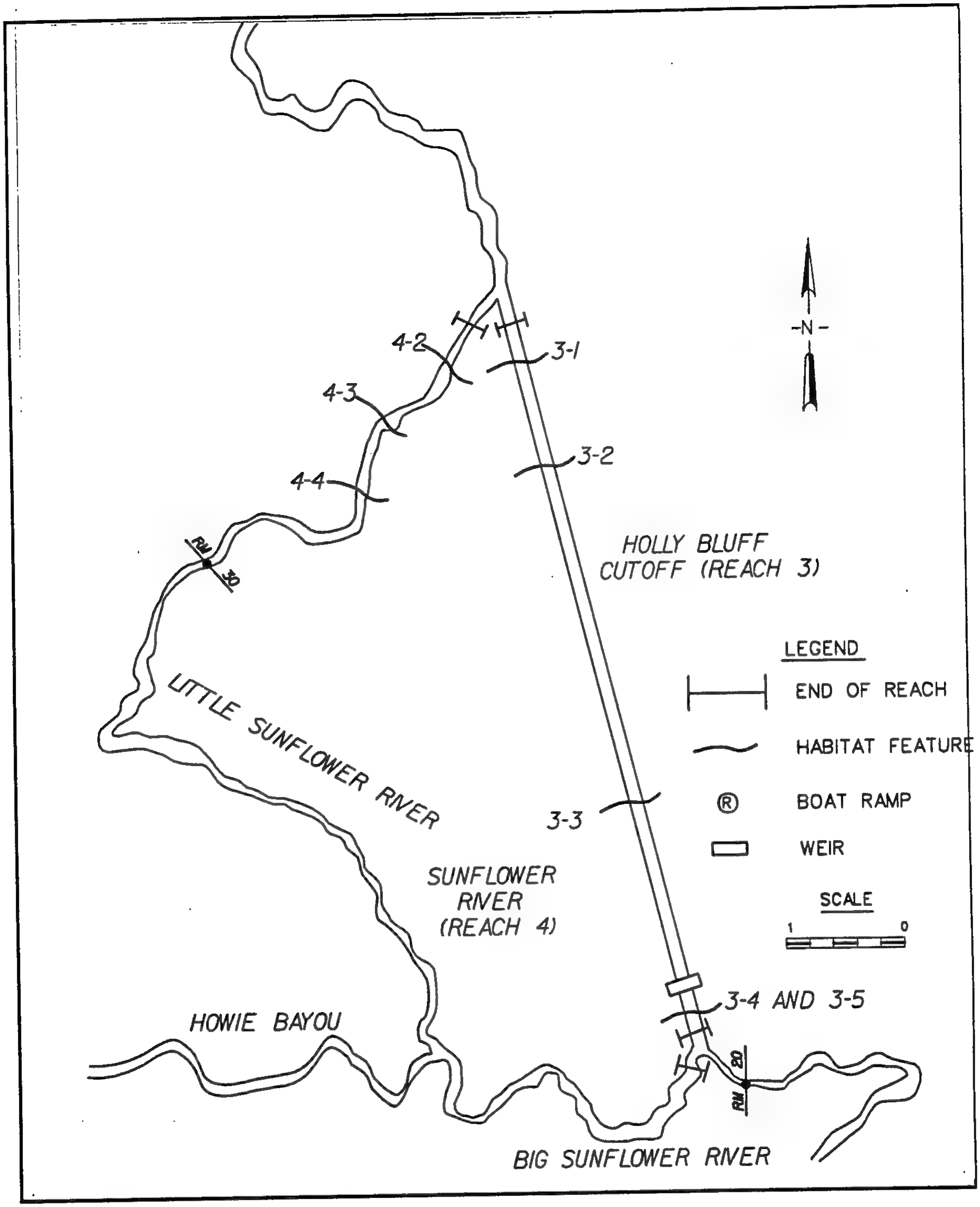

Figure 9. Reaches 3 and 4 of the Big Sunflower River Habitat Improvement Project that includes habitat features in Reach 3 specific to Plan 5

5 Future Considerations

Translocating Mussels

Background

The Team determined that it will be necessary to reseed some of the artificially placed substratum with mussels although some sites will be allowed to recolonize naturally. All mussels used to reseed sites will be taken from other locations in the Big Sunflower River, and none will be taken from other watersheds. The following is a brief discussion of methods required to successfully relocate mussels to new sites.

Collecting, holding, marking, and moving mussels

Cope and Waller (1993), Dunn (1993), and Layzer and Gordon (1993) have discussed mussel relocation methodology, monitoring strategy, and mussel relocation success (as judged by mortality). Gregory Cope has also summarized the available literature relative to mussel relocation projects and reports.[1] The following paragraphs summarize recommendations for seeding methodology relative to the Big Sunflower River project.

Areas to be seeded with mussels should be allowed to stabilize or "age" for at least 1 year prior to mussel transplant. This applies to all seeded areas including substrate enhancement sites, dike field/weir sites, and/or previously dredged sites. Maintenance dredging in the Big Sunflower River will proceed upriver. Downriver sites should be seeded with mussels from upriver sites that are next in line for dredging. The most upriver seeding sites should be seeded with mussels from upriver of the maintenance dredging project area.

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1 Personal Communication, 1994, Gregory Cope, U.S. Fish and Wildlife Service, La Crosse, WI.

Mussel collections and transplants should be performed during the spring of the year, preferably March - May as water levels and velocities allow. As an alternative, transplants could be performed October - December following cooling of water temperatures from summer maxima. Mussels should be hand collected by divers and placed in mesh holding bags in the river prior to transfer to the seeding site. Mussels should be transferred in large, well-aerated containers of river water immediately prior to placement at the seeding site. Water temperature in the transfer container should be maintained at or slightly below ambient water temperature. Transfer by boat is the most expedient method. Mussels should be replanted at the seeding site no more than 36 hr after initial removal from the home substrate.

Mussels should be marked with a single notch on both valves along the antero-ventral shell edge. Care should be taken to avoid injury to the mantle. Notching should be performed while in transit from the home site to the seeding site with care taken to minimize the time mussels are out of water and subjected to temperature extremes. Consideration can be given to numbered tagging individuals, but this is time-consuming and increases the time that mussels are subjected to stressful conditions.

Mussels should be placed in a natural orientation and depth within the substrate at the seeding site. Careful attempts should be made to distribute mussels evenly across the entire seeding site. A seeding density equalling 25 percent of the density of the nearest natural mussel bed is suggested. If densities at the seeding site have been recorded at 20/square meter, then seeding densities should be 5/square meter. Species composition percentages of seeded mussels should closely parallel that of nearest known beds.

Difficulties in judging the success of mussel relocations

The published literature acknowledges the difficulty in judging success of mussel relocations. Factors cited include the lack of direct evidence for mortality (i.e., marked dead individuals are not often found), difficulty in sampling exactly the same transect or quadrat in succeeding years, and changes in substrate stability that alter study sites and move mussels downstream.

Attention to placement of mussels evenly across the seeding site should reduce the need for relocating exact transects during resample efforts. Sufficient numbers of stratified, random samples should be taken to provide relatively low sampling error and allow comparison among sample years with a predetermined acceptable level of change. Sampling should be performed with replacement of mussels to the exact quadrat site following data gathering.

A sampling regime that monitors population status 1-, 5-, and 10-years postrelocation is recommended. The 1-year sample will primarily evaluate

relocation stress mortality and current induced removal/voluntary movement of mussels at the relocation site. One-year samples should be limited to diver searches of square meter quadrats without substrate removal since recruitment or retrieval of recruits at 1-year is unlikely. The 5- and 10-year samples should be designed to evaluate temporal and spatial changes in density, diversity, and size demographics utilizing the methods detailed by Miller et al. (1993) and Cawley (1993). Substrate removal replicates should be minimized to the maximum extent practicable at substrate improvement sites to reduce disturbance within the relatively small sites.

The number of sites to be monitored should include one of each enhancement type or combination of types within both Reach 1 and Reach 2. For example, if there are four substrate improvement sites only in Reach 1 and two in Reach 2, then one site in each reach should be monitored. In addition, reference sites outside the project impact zone (upriver sites) should be monitored to determine if nonproject related parameters (disease, flood, and senescence) are affecting mussel communities.

Recommendations for Protecting Mussels and Their Habitat in the Big Sunflower River

The Team prepared five plans that will minimize, to varying degrees, the impacts of channel maintenance on native freshwater mussels and their habitat. It is understood that personnel of the Vicksburg District may choose one of these plans, or a combination of these plans, and apply it to the river to minimize effects of dredging on mussels and their habitat. The Team makes the following recommendations:

a. The physical and biological effects of the chosen habitat improvement plan should be monitored at selected sites for at least 10 years after structures have been placed.

b. The existing dredging plan will be modified to protect as much mussel habitat as possible. This includes no-work areas (where dredging will not be done) and avoidance areas (where an attempt will be made to avoid mussels by dredging the lowest density areas). These areas have been identified in the habitat improvement plans. Prior to dredging, divers will mark the extent of important beds with buoys. This will minimize damage to the existing mussel resource.

The dredge cut will be as narrow and as deep as possible to concentrate all impacts to the center of the channel. The highest concentrations of mussels in the Big Sunflower River are in the depositional zones along both river banks.

6 Monitoring the Success of Habitat Improvement Features

Background

The purpose of the monitoring plan is to document the ability of habitat features (i.e., dikes, weirs, gravel substratum, and fish attractors) to provide physical, chemical, or biological conditions that benefit mussels. For example, dike fields shunt water to the opposite bank and increase velocity and will help keep substratum sediment free during most of the year. This should maintain overall mussel species richness and increase species diversity and recruitment levels at specific sites. Fish attractors provide a substratum for aquatic insects and periphyton. These will attract fish, which are hosts for freshwater mussels. It will be possible to determine if dikes or weirs immediately affect water velocity and substratum characteristics. However, the biological effects of these features may not be apparent for months or years. Periphyton should colonize attractors within months, aquatic insects should colonize within months or years, and mollusc recruitment in the surrounding substratum may not be measurable for 5 or more years.

The seasonal aspect of these studies cannot be ignored. Physical and chemical attributes of water are affected by stage height, water temperature, and season. Water velocity should be measured during different stage heights, although mollusc recruitment could be monitored once a year or every other year.

The proposed monitoring program is actually a set of controlled field experiments. Physical, chemical, and biological data will be compared with information collected in unimproved river reaches. In addition, studies will be designed to determine if predicted changes brought about by these habitat features were accurate.

Not all parameters must be monitored regularly for the life of the project. Relationships between stage height and velocity will not need to be

verified each year. Not all habitat features have to be studied; for example, a subset of attractors can be monitored to assess fish and invertebrate usage.

Studies will be designed to obtain qualitative and quantitative information. At some sites, diver inspection may suffice to determine if the substratum is sediment free. At other sites, core or ponar grab samples can be collected and the material analyzed for organic and water content and grain-size distribution. Black and white ground-level photography could provide information on bank stability and vegetative growth.

The following details information on the parameters that will be measured to judge the success of habitat features at the Big Sunflower River. Proposed studies can be modified when the details of the habitat improvement plan are complete.

Parameters to Monitor

Terrestrial conditions

At least once a year, each site with a habitat improvement structure will be inspected visually. Photographs will be taken to document conditions on both banks for a distance 100 ft upriver and downriver of the feature. The site will also be visually inspected for loss of vegetation, bank erosion, or accumulation of trash or logs. A global position system will be used to permanently identify study sites.

Photography will then be compared with pictures collected during previous years. If signs of disturbance are noted, then an additional site visit may be required. Appropriate personnel will be contacted to make a determination of the cause of the problem and suggest solutions. If necessary, the area will be further stabilized or protected.

Underwater conditions (diver inspections)

At least two divers will inspect each major underwater feature (gravel, dikes, weirs, and at least some attractors) immediately after placement. Divers will obtain information on stability of the feature, sediment accretion, or erosion. If necessary, divers will permanently mark a site with a rod and record latitude and longitude with a global positioning system. Each major feature will be inspected at least once a year.

Water velocity

Water velocity will be measured with a Marsh McBirney 527 current velocity meter coupled to a Campbell Scientific data logger. This equipment will allow for collection of water velocity data on an X and Y axis at 1-sec intervals. Data will be stored and used later for plotting and statistical analysis. The probe of the current velocity meter will be placed at various distances upriver and downriver of the habitat feature. Velocity data will be collected for a minimum of 5 min at each location. If necessary, up to four velocity probes can be deployed simultaneously.

Water velocity data will be collected at each major habitat feature at low, moderate, and high stage. Field-collected data will be compared with predictions of water velocity made prior to construction.

Substratum conditions

Divers will collect sediments at specific sites at each major feature. Samples will be returned to the laboratory for analysis of grain-size distribution and organic and water content. Results will be compared with samples of material collected immediately after placement.

Sedimentation rates will also be assessed by having a diver inspect graduated rods driven into the substratum at selected sites on gravel bars. The graduated rods provide a rapid method for determining sediment deposition or accretion. Graduations will be etched in the rod so there will be no need for visual inspection.

Water quality

Elevated water temperature can stress aquatic biota and cause reduced physical condition and fecundity. At selected sites, water temperature at the substratum-water interface will be measured with a Ryan recording thermometer. This instrument can record and store data at 5-sec intervals for periods up to 24 hr.

Reduced levels of dissolved oxygen during periods of elevated temperatures at night can stress aquatic organisms. Diurnal measurements of dissolved oxygen will be obtained near the substratum-water interface with a Yellow Springs Dissolved Oxygen meter.

Although many water quality parameters can potentially affect freshwater mussels, pH and dissolved calcium are usually important in the distribution and abundance of these organisms. Water samples will be taken in association with proposed habitat improvement features for measurement of dissolved calcium and pH.

Total dissolved solids, total suspended solids, and turbidity will be measured at selected sites. Although suspended solids are a potential source of food for the freshwater mussels, elevated concentrations of suspended inorganic material can potentially stress mussels.

Freshwater mussels

Quantitative and qualitative methods will be used to collect freshwater mussels at sites affected and unaffected by the habitat improvement features. The sampling plan for mussels is designed to obtain information on total density, size demography of dominant species, species richness, species diversity, evenness, and community composition. This information will be used to determine if the predetermined goals of the habitat improvement plan are being met. More detailed information on sampling methods can be found in Miller et al. (1993).

Reconnaissance dives will be made at several sites at each study area. Two divers will spend 10 to 30 min at each site and relay information to the tender on current velocity, bottom type, and the presence of dead shells and live mussels. Estimates of the number of live mussels per square meter will be made.

Quantitative samples will be obtained with a 0.25-sq m quadrat (50 cm on a side), constructed of 0.6- by 100-mm aluminum stock. Quadrats will be placed approximately 1 m apart and arranged in a 2-by-5 matrix. Two divers will collect simultaneously, working their way upriver. Each diver scoops out all sand, gravel, live mussels, and shells out of the 0.25-sq m quadrat and places material into a 20-L bucket. The bucket is pulled to the surface with a gasoline-powered winch and transported to shore. Sediments from each quantitative sample are washed through three nested box screens (40- by 66-cm) with mesh measuring 6.35, 12.7, and 34 mm on a side. Live bivalves are picked from the sediments and placed in prelabeled zipper lock bags. After all mussels have been removed from each screen, total sediment in each size fraction is weighed with a portable balance. The percentage of particles in each size fraction are obtained for each quantitative sample.

As an alternative to total substratum sampling, a diver-operated suction pump will be used. The suction pump is faster than collecting total substratum samples; however, specific information on substratum composition cannot be easily obtained using this method. Both sampling techniques will probably be used on this project.

After all live bivalves have been removed from sediments, each will be identified and total shell length measured. Nomenclature will be consistent with Turgeon et al. (1988). If there is not enough time to process in the field, mussels will be preserved in buffered 10-percent formalin and returned to the laboratory for analysis. Uncommon, Threatened, or

Endangered species (U.S. Fish and Wildlife Service 1991) will be returned to the river unharmed.

It is anticipated that a minimum of two sites at each bed will be chosen for detailed study. At each site, two to three subsites, each separated by 5 to 10 m, will be identified. Ten quantitative samples will be collected at each subsite using either the total substratum removal method or the suction dredge. To the extent possible, sites will differ with respect to water velocity, depth, and substratum conditions.

Qualitative sampling consists of having a diver collect live mussels by hand without bias regarding species or size. In large rivers, this is done by feel since visibility is limited or nonexistent. Two divers working simultaneously will collect a total of 12 samples (nylon bags of mussels) at each site. Five mussels are placed in each of three bags, and twenty mussels are placed in each of nine bags. Approximately 185 mussels are collected at each site, although numbers vary since divers sometimes retrieve dead organisms or rocks. Depending on local conditions, qualitative samples will be taken at three to five sites on each mussel bed.

Physical and reproductive condition of freshwater mussels

The effectiveness of the habitat improvement plan on the Sunflower River can be assessed by regularly determining the physiological condition and reproductive effort of the mussels. This approach is particularly useful because results are quantitative and can be used to make intersite comparisons. The long-term effectiveness of different strategies for improving habitat can be compared.

The relative condition of mussels will be determined using several indicators of health and reproduction. These indicators include tissue content, glycogen concentration, and DNA and lipid contents. Tissue content, the amount of soft tissue per unit shell size, is an integrative parameter that reflects the growth status of mussels. It is positively correlated with health; mussels living in high-quality habitats are expected to have higher tissue content than mussels from less suitable habitats.

Glycogen is an important source of nutrient reserve in bivalves. It is synthesized and stored during periods of positive energy balance when energy derived from feeding exceeds maintenance requirements. The stored glycogen provides energy for gamete synthesis during the reproductive season and also provides energy during periods of environmental stress. Glycogen concentration, the amount stored relative to other soft tissue components, provides a quantitative measure of the condition of mussels. In high-quality habitats, mussels are expected to have increased glycogen storage.

DNA contains genetic information and is present in all living cells in mussels. It is found in especially high concentration in sperm. The

amount of DNA per unit shell size can be used as a quantitative measure of reproductive effort in male bivalves. Males from high-quality habitats should have more energy available for reproduction and thus have greater DNA content than mussels from poor habitats.

Lipids, particularly triacylglycerol and cholesterol, are stored in the ova during gamete synthesis and are used as fuel during subsequent embryonic development. In conjunction with DNA content in males, lipid content of the visceral mass in females can be used as a measure of reproductive effort. Female mussels from improved habitats should have increased lipid content, indicating greater reproductive effort.

Reproductive effort will also be measured directly by determining the number of glochidia being brooded in the gills of selected mussels. The reproductive cycle of native unionids includes a phase during which ova in female mussels are fertilized internally and brooded for a period of time in the gills. The gills from these mussels will be solubilized by digestion with an enzyme to liberate the glochidia or larvae that can then be counted directly.

A survey will be conducted to determine the health and reproductive condition of the mussels from different locations in the Sunflower River under existing conditions. In addition, bimonthly samples will be obtained during the first year to determine periods of reproductive activity. After implementation of the habitat improvement plan, regular sampling of the mussels to determine physiological condition will be conducted quarterly in May, August, November, and February. Mussel sampling to determine reproductive effort will center around periods of peak reproductive activity. These periods are species specific and will be determined after the initial survey.

Fish

Fishes will be sampled at peak abundance (during and immediately following spawning seasons) and during pronounced and progressive changes in physical habitat (e.g., summer declines in water level). Adult and juvenile fishes will be collected with a 10- by 8-ft seine with 3/16-in. mesh; standard effort will be 10 hauls stratified among all apparent macrohabitats. Large, demersal fishes will be collected with gill nets (90- by 6-ft with 0.75-, 1.5-, 2.0-, 2.5-, 3.0-, 3.5-in. mesh) and hoop nets (15-ft-long, 3-ft-diam, 1-in.-square mesh). Standard efforts will be overnight sets of one to two gill nets secured at oblique angles to shore during low velocity, or three hoop nets placed near shore and midchannel during high-water velocity. During the reproductive period, larval fish will be collected with light traps in littoral areas. Eggs and larvae will be collected with suction pumps by sweeping interstitial spaces of riprap and mussel beds.

Selected adult fish will be examined for glochidia. Small fishes will be preserved in 10-percent formalin. Larger fishes will be identified in the field and released. In the laboratory, fishes will be washed, identified, and counted. Specimens will be catalogued and deposited as holdings in the Northeast Louisiana University Museum of Zoology or retained for collections at the Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station and Mississippi Department of Wildlife, Fisheries, and Parks Museum of Natural Science.

During each fish survey, dissolved oxygen, temperature, pH, and conductivity will be measured using a Hydrolab or Cole-Palmer probes. Turbidity will be measured with a Hach 2100P turbidimeter. Stream width will be measured using a Lietz rangefinder. Water depth and velocity will be measured at 10 points along cross-sectional transects using a stadia rod (<20 ft) or Hummingbird depth recorder (>20 ft), and a Marsh-McBirney Flo-Mate 2000. Velocity will be measured at a point 60 percent from the water's surface (depths < 3 ft), or 20 and 80 percent (depths > 3 ft).

Fish species-abundance data will be compiled for each station and date and used to quantify species diversity and relative species abundance (the percentage abundance of each species present). The Shannon index (H′) is a heterogeneity index sensitive to richness (number of species) and evenness (equitability of abundance among species) components of diversity (Magurran 1988). Values are not expressed relative to sample size and are appropriate for characterizing individual collections, even when numbers of individuals are comparatively low (<100); values range from 0.00 (only one species present) to ln[S], where S = number of species in that sample. Rarefaction is a technique that allows diversity to be expressed as the number of species expected from a random subsample of predetermined size; it compensates for disparities in total numbers collected and provides direct inference of differences in species richness (Ludwig and Reynolds 1988). Rarefaction requires large and comprehensive data sets, so analyses will be performed with pooled data for three groups of stations.

Descriptions of fish-habitat relationships will be expressed for the community and for individual species. To identify habitat variables influencing the community (and the greatest number of species), multiple regressions will be generated using diversity measures as dependent variables and physical habitat parameters as independent variables. The Shannon index (H′) will be used to characterize shoreline assemblages; species richness (S) will be used to characterize demersal assemblages (low catch obscures estimates of evenness). Physical habitat parameters will be those measured during fish surveys (water quality and hydraulic variables), area of structural features obtained from project specifications of improvement device, and standardized river stage (river stage for that day - minimum recorded river stage). A technique will be used that accounts for maximum variance (RMAX) while limiting final equations to no more than four variables (SAS 1985). To describe habitats of individual species, relative abundance data for each species will be used to weight

concurrent measurements of habitat data and provide weighted mean values of physical parameters.

Nonmolluscan Invertebrates

Invertebrates in rivers generally live either embenthically (=infauna) or epibenthically. Embenthic refers to living in, i.e., penetrating the substratum; marine biologists often use the term infauna to describe the biota living in the bottom substrates. For example, in the Sunflower River, the silt substuatua, which cover much of the bottom and are being dredged to improve water flow, contain embenthic invertebrates. Epibenthic organisms live on but not in the substrates. In the Sunflower River, snags or riprap would be colonized by epibenthic organisms. Usually there is very little overlap between the two groups; i.e, generally, particular species of aquatic invertebrates live either embenthically or epibenthically, but not both. A monitoring plan for nonmolluscan invertebrates will include both groups of organisms.

Embenthic organisms will first be sampled before any dredging begins, since operational effects can only be determined if the makeup of the preoperational community is known. Based on information concerning the river from previous surveys, the various substrates present in the river bottom will be stratified by type. Each substratum type will be sampled at each of two locations using a petite Ponar sampler. Sampling within a substratum will be performed along a transect. Bottom samples will be sieved using either a U.S. No. 30 or U.S. No. 35 sieve. Once one of the two sieve sizes is selected, it will be used throughout the study. Invertebrates will be removed from the substratum and first separated into broad taxonomic groups. They may then be identified to a lower level where further detail is warranted. Invertebrate community composition and densities will be determined. Autumn is the optimal time for sampling embenthic invertebrates since the bulk of aquatic insect emergence will probably already have taken place and generally existent low-water conditions expedite sampling.

Embenthic invertebrate sampling locations will be selected after evaluating possible effects of dredging or other modifications on invertebrate communities. Sampling will be performed using the same procedures used before dredging. Since invertebrate colonization will take several years, and habitats will change, at least 10 years of invertebrate sampling will be conducted.

The use of woody material or PVC by invertebrates will be determined by suspending short lengths of the materials from floats in the Sunflower River. Following a suitable colonization period, the materials will be retrieved, the invertebrates will be collected and identified, and invertebrate composition and densities determined. Both slow and fast-water sites will be monitored since the composition of epibenthic invertebrates depends on current velocity (Beckett and Miller 1982).

Reporting Results

A progress report will be prepared and submitted at the completion of the field work. This will include a description of all tasks completed, problems encountered, and a brief summary of major findings. Within 9 months, a draft report, which will include Abstract, Introduction, Results, Discussion, and Literature Cited, will be submitted to the sponsor. The report will include information on habitat conditions, characteristics of the nonmolluscan bivalves, mussels, and fishes. Reports will be sent to the U.S. Army Engineer District, Vicksburg, the U. S. Fish and Wildlife Service, and the Mississippi Department of Wildlife, Fisheries and Parks. The team that developed the habitat rehabilitation plan could review and comment on findings from monitoring.

Schedule

Detailed information on the schedule of sampling for various parameters will be prepared when the final habitat mitigation plan has been chosen. However, the Team recommended that habitat features be monitored for at least 10 years. In addition, the Team recommended that limited baseline information be gathered for some parameters in 1995-96 to provide information needed to assess effects of dredging and placement of new structures. Only limited sampling will be required since considerable data on fishes and mussels has been collected previously.

As described above, not all parameters will have to be measured each year at each location. Physical and chemical parameters will be assessed regularly during the first few years after construction. After quantitative information on sediment and water velocity is collected, diver inspections will probably provide needed data. Conversely, diver inspections could provide the necessary information on mussels during the first years after construction of the habitat features. Detailed qualitative and quantitative sampling will not be necessary if results of an initial reconnaissance survey indicates that mussels are not present at a site.

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Appendix A
Estimated Costs for Habitat Features for Plan 1

Table A1
Plan 1, Reach 1

Item	Cost, $
RM 75.6; Site 1-1	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 71.6; Site 1-2	
Avoidance Area	0
Fish Attractors (4)	2,000
RM 68.6; Site 1-3	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 66.6; Site 1-4	
Dike Field	15,881
Bank Stabilization (800 ft)	72,000
Weir	6,353
Revegetation (800 by 50 ft)	2,111
RM 61.6; Site 1-5	
Dike Field	15,881
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 56.1; Site 1-6	
Avoidance Area	0
Fish Attractors (4)	2,000
Total	626,380

Summary for Reach 1

Habitat Feature	Cost, $	%	Number
Dike Fields	63,524	10.1	4
Weirs	25,412	4.1	4
Attractors	16,000	2.6	32
Bank Stabilization (800 ft)	288,000	46.0	4
Revegetation (800 by 50 ft)	8,444	1.3	4
Substratum Improvement	225,000	35.9	4
Total	626,380	100.0	

Table A2
Plan 1, Reach 2

RM 53.9-54.1 (Existing Bed); Site 2-1	Cost, $
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
RM 41.6-44.6; Sites 2-2 and 2-3	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 44.6-48.6; Sites 2-4 and 2-5	
Dike Field	15,881
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 27.8 (Existing Bed); Site 2-6	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
Total	392,190

Summary for Reach 2

Habitat feature	Cost, $	%	Number
Dike Fields	31,762	8.1	2
Weirs	12,706	3.2	2
Attractors	12,000	3.1	24
Bank Stabilization (800 ft)	144,000	36.7	2
Revegetation (800 by 50 ft)	4,222	1.1	2
Substratum Improvement	187,500	47.8	4
Total	392,190	100.0	

Table A3
Plan 1, Reach 3

Miles from Upriver end of Cutoff:	
+0.5; Site 3-1	Cost, $
Substratum Improvement (500 ft)	37,500
Revegetation (500 by 50 ft)	1,882
Fish Attractors (4)	2,000
+1.0; Site 3-2	
Substratum Improvement (500 ft)	37,500
Revegetation (500 by 50 ft)	1,882
Fish Attractors (4)	2,000
+1.5; Site 3-3	
Substratum Improvement (500 ft)	37,500
Revegetation (500 by 50 ft)	1,882
+2.0; Site 3-4	
Substratum Improvement (500 ft)	37,500
Revegetation (500 by 50 ft)	1,882
Total	161,528

Summary for Reach 3

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	4,000	2.5	8
Bank Stabilization (800 ft)	0	0.0	0
Revegetation (500 by 50 ft)	7,528	4.7	4
Substratum Improvement	150,000	92.9	4
Total	161,528	100.0	

Table A4
Plan 1, Reach 4

Item	Cost, $
RM 34.5; Site 4-1	
Avoidance Area	0
Substratum Improvement (500 ft)	37,500
Fish Attractors (4)	2,000
RM 34.0; Site 4-2	
Substratum Improvement (500 ft)	37,500
RM 33.0; Site 4-3	
Substratum Improvement (500 ft)	37,500
Fish Attractors (4)	2,000
RM 32.0; Site 4-4	
Substratum Improvement (500 ft)	37,500
Total	154,000

Summary for Reach 4

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	4,000	2.6	8
Bank Stabilization (800 ft)	0	0.0	0
Revegetation (800 by 50 ft)	0	0.0	0
Substratum Improvement	150,000	97.4	4
Total	154,000	100.0	

Note: These are "unimproved" river miles directly from the topographic maps.

Table A5
Summary of Habitat Features for Plan 1

Location	Costs, $	%
Reach 1	626,380	47.0
Reach 2	392,190	29.4
Reach 3	161,528	12.1
Reach 4	154,000	11.5
Reach 5	0	0.0
Total	1,334,098	100.0

Habitat feature	Number	Costs, $	%
Dike Fields	6	95,286	7.14
Weirs	6	38,118	2.86
Attractors	72	36,000	2.70
Bank Stabilization	6	432,000	32.38
Revegetation	10	20,194	1.51
Substratum Improvement	16	712,500	53.41
Total	116	1,334,098	100.00

Appendix B
Estimated Costs for Habitat Features for Plan 2

Table B1
Plan 2, Reach 1

Item	Cost, $
RM 75.6; Site 1-1	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Revegetation (800 by 50 ft)	2,111
RM 71.6; Site 1-2	
Avoidance Area	0
Fish Attractors	2,000
RM 68.6; Site 1-3	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Revegetation (800 by 50 ft)	2,111
RM 66.6; Site 1-4	
Dike Field	15,881
Bank Stabilization (800 ft)	72,000
RM 61.6; Site 1-5	
Dike Field	15,881
Bank Stabilization (800 ft)	72,000
RM 56.1; Site 1-6	
Avoidance Area	0
Fish Attractors (4)	2,000
Total	498,746

Summary for Reach 1

Habitat Feature	Cost, $	%	Number
Dike Fields	63,524	12.7	4
Weirs	0	0.0	0
Attractors	8,000	1.6	16
Bank Stabilization (800 ft)	288,000	57.7	4
Revegetation (800 by 50 ft)	4,222	0.8	2
Substratum Improvement	135,000	27.1	2
Total	498,746	100.0	

Table B2
Plan 2, Reach 2

	Cost, $
RM 53.9-54.1 (Existing Bed); Site 2-1	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
RM 41.6-44.6; Sites 2-3 and 2-4	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800)	72,000
Revegetation (800 by 50 ft)	2,111
RM 44.6-48.6; Sites 2-4 and 2-5	
Dike Field	15,881
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Revegetation (800 by 50 ft)	2,111
RM 27.8 (Existing Bed); Site 2-6	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
Total	330,484

Summary for Reach 2

Habitat Feature	Cost, $	%	Number
Dike Fields	31,762	9.6	2
Weirs	0	0.0	0
Attractors	8,000	2.4	16
Bank Stabilization (800 ft)	144,000	43.6	2
Revegetation (800 by 50 ft)	4,222	1.3	2
Substratum Improvement	142,500	43.1	3
Total	330,484	100.0	

Table B3
Plan 2, Reach 3

Distance from Upriver end of Cutoff:	Cost, $
+0.5 Miles; Site 3-1	
Substratum Improvement (500 ft)	37,500
Revegetation (500 by 50 ft)	1,882
Fish Attractors (4)	2,000
+1.0 Miles; Site 3-2	
Substratum Improvement (500)	37,500
Revegetation (500 by 50 ft)	1,882
Fish Attractors (4)	2,000
+1.5 Miles; Site 3-3	
Substratum Improvement (500)	37,500
Revegetation (500 by 50 ft)	1,882
+2.0 Miles; Site 3-4	
Substratum Improvement (500)	37,500
Revegetation (500 by 50 ft)	1,882
Total	161,528

Summary for Reach 3

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	4,000	2.5	8
Bank Stabilization (800 ft)	0	0.0	0
Revegetation (500 by 50 ft)	7,528	4.7	4
Substratum Improvement	150,000	92.9	4
Total	161,528	100.0	

Table B4
Plan 2, Reach 4

Item	Cost, $
RM 34.5; Site 4-1	
Avoidance Area	0
Substratum Improvement (500)	37,500
Fish Attractors (4)	2,000
RM 34.0; Site 4-2	
Substratum Improvement (500)	37,500
RM 33.0; Site 4-3	
Substratum Improvement (500)	37,500
Fish Attractors (4)	2,000
RM 32.0; Site 4-4	
Substratum Improvement (500)	37,500
Total	154,000

Summary for Reach 4

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	4,000	2.6	8
Bank Stabilization (800 ft)	0	0.0	0
Revegetation (800 by 50 ft)	0	0.0	0
Substratum Improvement	150,000	97.4	4
Total	154,000	100.0	

Note: These are "unimproved" river miles directly from the topographic maps.

Table B5
Summary of Habitat Features for Plan 2

Location	Costs, $	%
Reach 1	498,746	43.6
Reach 2	330,484	28.9
Reach 3	161,528	14.1
Reach 4	154,000	13.5
Reach 5	0	0.0
Total	1,144,758	100.0

Habitat Feature	Number	Costs, $	%
Dike Fields	6	95,286	8.32
Weirs	0	0	0.00
Attractors	48	24,000	2.10
Bank Stabilization	6	432,000	37.74
Revegetation	8	15,972	1.40
Substratum Improvement	13	577,500	50.45
Total	81	1,144,758	100.00

Appendix C
Estimated Costs for Habitat Features for Plan 3

Table C1
Plan 3, Reach 1

Item	Cost, $
RM 75.6; Site 1-1	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 71.6; Site 1-2	
Avoidance Area	0
Fish Attractors (4)	2,000
RM 66.6; Site 1-3	
Dike Field	15,881
Bank Stabilization (800 ft)	72,000
Weir	6,353
RM 56.1; Site 1-4	
Avoidance Area	0
Fish Attractors (4)	2,000
Total	311,079

Summary for Reach 1

Habitat Feature	Cost	%	Number
Dike Fields	31,762	10.2	2
Weirs	12,706	4.1	2
Attractors	8,000	2.6	16
Bank Stabilization (800 ft)	144,000	46.3	2
Revegetation (800 by 50 ft)	2,111	0.7	1
Substratum Improvement	112,500	36.2	2
Total	311,079	100.0	

Table C2
Plan 3, Reach 2

RM 53.9-54.1 (Existing Bed); Site 2-1	Cost, $
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
RM 41.6-44.6; Sites 2-3 and 2-4	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 27.8 (Existing Bed); Site 2-6	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
Total	291,845

Summary for Reach 2

Habitat Feature	Cost	%	Number
Dike Fields	15,881	5.4	1
Weirs	6,353	2.2	1
Attractors	8,000	2.7	16
Bank Stabilization (800 ft)	72,000	24.7	1
Revegetation (800 by 50 ft)	2,111	0.7	1
Substratum Improvement	187,500	64.2	4
Total	291,845	100.0	

Table C3
Summary of Plan 3

Location	Cost, $	%
Reach 1	311,079	51.6
Reach 2	291,845	48.4
Reach 3	0	0.0
Reach 4	0	0.0
Reach 5	0	0.0
Total	602,924	100.0

Habitat Feature	Number	Cost, $	%
Dike Fields	3	47,643	7.90
Weirs	3	19,059	3.16
Attractors	32	16,000	2.65
Bank Stabilization	3	216,000	35.83
Revegetation	2	4,222	0.70
Substratum Improvement	6	300,000	49.76
Total	49	602,924	100.00

Appendix D
Estimated Costs for Habitat Features for Plan 4

Table D1
Plan 4, Reach 1

Item	Cost, $
RM 75.6; Site 1-1	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 71.6; Site 1-2	
Avoidance Area	0
Fish Attractors (4)	2,000
RM 68.6; Site 1-3	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 66.6:Site 1-4	
Dike Field	15,881
Bank Stabilization (800 ft)	72,000
Weir	6,353
Revegetation (800 by 50 ft)	2,111
RM 61.6; Site 1-5	
Dike Field	15,881
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 56.1; Site 1-6	
Avoidance Area	0
Fish Attractors (4)	2,000
Total	626,380

Summary for Reach 1

Habitat Feature	Cost	%	Number
Dike Fields	63,524	10.1	4
Weirs	25,412	4.1	4
Attractors	16,000	2.6	32
Bank Stabilization (800 ft)	288,000	46.0	4
Revegetation (800 by 50 ft)	8,444	1.3	4
Substratum Improvement	225,000	35.9	4
Total	626,380	100.0	

Table D2
Plan 4, Reach 2

	Cost, $
RM 53.9-54.1 (Existing Bed): Site 2-1	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
RM 41.6-44.6; Sites 2-2 and 2-3	
Dike Field	15,881
Substratum Improvement (900 ft)	67,500
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Substratum Improvement (300 ft)	45,000
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 44.6-48.6; Sites 2-4 and 2-5	
Dike Field	15,881
Fish Attractor (4)	2,000
Bank Stabilization (800 ft)	72,000
Weir	6,353
Fish Attractor (4)	2,000
Revegetation (800 by 50 ft)	2,111
RM 27.8 (Existing Bed); Site 2-6	
No-Work Area	0
Fish Attractor (4)	2,000
Substratum Improvement (500 ft)	37,500
Total	392,190

Summary for Reach 2

Habitat Feature	Cost, $	%	Number
Dike Fields	31,762	8.1	2
Weirs	12,706	3.2	2
Attractors	12,000	3.1	24
Bank Stabilization (800 ft)	144,000	36.7	2
Revegetation (800 by 50 ft)	4,222	1.1	2
Substratum Improvement	187,500	47.8	4
Total	392,190	100.0	

Table D3
Summary of Plan 4

Location	Cost, $	%
Reach 1	626,380	61.5
Reach 2	392,190	38.5
Reach 3	0	0.0
Reach 4	0	0.0
Reach 5	0	0.0
Total	1,018,570	100.0

Habitat Feature	Number	Cost, $	%
Dike Fields	6	95,286	9.35
Weirs	6	38,118	3.74
Attractors	56	28,000	2.75
Bank Stabilization	6	432,000	42.41
Revegetation	6	12,666	1.24
Substratum Improvement	8	412,500	40.50
Total	88	1,018,570	100.00

Appendix E
Estimated Costs for Habitat Features for Plan 5

Table E1
Plan 5, Reach 1

Item	Cost, $
RM 75.6; Site 1-1	
Dike Field (3 dikes)	9,529
Substratum Improvement (600 ft)	45,000
Fish Attractor (4)	2,000
Bank Stabilization (500 ft)	47,250
RM 71.6; Site 1-2	
Avoidance Area	0
Fish Attractors (4)	2,000
RM 68.6; Site 1-3	
Dike Field (3 dikes)	9,529
Substratum Improvement (600 ft)	45,000
Fish Attractor (4)	2,000
Bank Stabilization (500 ft)	47,250
RM 56.1; Site 1-6	
Avoidance Area	0
Fish Attractors (4)	2,000
Total	211,558

Summary of Major Features	Cost, $	%	Number
Dike Fields (3 dikes)	19,058	9.0	2
Attractors	8,000	3.8	16
Bank Stabilization (500 ft)	94,500	44.7	2
Substratum Improvement	90,000	42.5	2
Total	211,558	100.0	

Table E2
Plan 5, Reach 2

	Cost, $
RM 53.9-54.1 (Existing Bed); Site 2-1	
No-Work Area	0
Fish Attractor (4)	2,000
RM 27.8 (Existing Bed); Site 2-6	
No-Work Area	0
Fish Attractor (4)	2,000
Total	4,000

Summary of Major Features	Cost, $	%	Number
Attractors	4,000	100.0	8
Total	4,000		

Table E3
Plan 5, Reach 3

Miles from Upriver end of Cutoff:	Cost, $
+0.5; Site 3-1	
Substratum Improvement (200 by 25 ft)	3,750
Fish Attractors (2)	1,000
+1.5; Site 3-2	
Substratum Improvement (200 by 25 ft)	3,750
Fish Attractors (2)	1,000
+5.0; Site 3-3	
Substratum Improvement (200 by 25 ft)	3,750
Fish Attractors (2)	1,000
200 ft Downriver of Weir; Site 3-4	
Substratum Improvement (200 by 25 ft)	3,750
Fish Attractors (2)	3,750
800 ft Downriver of Weir; Site 3-5	
Substratum Improvement (200 by 25 ft)	3,750
Fish Attractors (2)	3,750
Total	29,250

Summary for Reach 3

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	10,500	35.9	20
Bank Stabilization	0	0.0	0
Revegetation	0	0.0	0
Substratum Improvement	18,750	64.1	5
Total	29,250	100.0	

Note: These sites appear on Figure 9.

Table E4
Plan 5, Reach 4

Item	Cost, $
RM 34.5; Site 4-1	
Avoidance Area	0
Fish Attractors (2)	1,000
RM 32.0; Site 4-4	
Fish Attractors (2)	1,000
Total	2,000

Summary for Reach 4

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	2,000	100.0	4
Bank Stabilization	0	0.0	0
Revegetation	0	0.0	0
Substratum Improvement	0	0.0	0
Total	2,000	100.0	

Note: These are "unimproved" river miles directly from the topographic maps.

Table E5
Plan 5, Reach 5

Item	Cost, $
RM 20.0; Site 5-1	
Fish Attractors (2)	1,000
RM 17.0; Site 5-2	
Fish Attractors (2)	1,000
RM 15.0; Site 5-3	
Fish Attractors (2)	1,000
Total	3,000

Summary for Reach 5

Habitat Feature	Cost, $	%	Number
Dike Fields	0	0.0	0
Weirs	0	0.0	0
Attractors	3,000	100.0	6
Bank Stabilization (800 ft)	0	0.0	0
Revegetation (800 by 50 ft)	0	0.0	0
Substratum Improvement	0	0.0	0
Total	3,000	100.0	

Table E6
Summary of Plan 5

Location	Cost, $	%
Reach 1	211,558	84.7
Reach 2	4,000	1.6
Reach 3	29,250	11.7
Reach 4	2,000	0.8
Reach 5	3,000	1.2
Total	249,808	100.0

Habitat Feature	Number	Cost, $	%
Dike Fields (3 Dikes)	2	19,058	7.63
Weirs	0	0	0.00
Attractors	54	27,500	11.01
Bank Stabilization (500 ft)	2	94,500	37.83
Revegetation	0	0	0.00
Substratum Improvement	7	108,750	43.53
Grand Total	65	249,808	100.00

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13. ABSTRACT *(Maximum 200 words)*

A multidisciplinary team, consisting of biologists and engineers from the Mississippi Department of Wildlife, Fisheries and Parks, the U.S. Fish and Wildlife Service, the University of Southern Mississippi, the U.S. Army Engineer District, Vicksburg, and the U.S. Army Engineer Waterways Experiment Station, prepared five habitat improvement plans for the Big Sunflower River, Mississippi. Plans were designed to mitigate for the negative effects of maintenance dredging on freshwater mussels (Family: Unionidae) and their habitat. The goals of the Habitat Improvement Team were to (a) maintain existing mussel species richness and to improve species diversity and recruitment levels of the community, (b) improve overall substratum conditions for the freshwater mussels at selected reaches, and (c) obtain information that can be used to improve other low-gradient rivers in the South.

The Big Sunflower River has been altered considerably since the early 1900s. Most notable alterations include a 7.4-mile-long channel cutoff constructed in 1959 and channel maintenance and dredging completed in the early 1960s. The river flows through agricultural land and is characterized by the presence of deep deposits of fine sand and silt (often greater than 2 ft deep) along much of the shore. Mussel fauna in the river is dominated by the threeridge

(Continued)

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(*Amblema plicata plicata*) (49.1 to 90.0 percent), followed by the pimpleback (*Quadrula pustulosa pustulosa*) (2.0 to 19.4 percent), and the bankclimber (*Plectomerus dombeyanus*) (3.5 to 29.0 percent). Species richness at selected beds (9 to 12 species) and species diversity (the Shannon index (H′), 0.49 to 1.46) were low. At selected sites, mean density (individuals/square meter) ranged from 28.6 (±2.8, ±Standard Error) to 235.0 (±16.0) and mean biomass (grams/square meter) ranged from 6,590.8 (±636.1) to 52,250.1 (±3,284.8). There was virtually no evidence of recent recruitment for any species; less than 1 percent were less than 30-mm total length. No endangered species were found, although *Pleurobema pyramidatum*, uncommon in the river, is a candidate for inclusion on the Federal list of Threatened or Endangered species.

The Habitat Improvement Team recommended the following improvement features: (a) dike fields with either three or five dikes, (b) low-water weirs that reach completely across the river, (c) gravel bars, (d) structures made of polyvinyl chloride pipe or logs to attract invertebrates and fishes, (e) no-work areas where no dredging will occur, and (f) avoidance areas where dredging will be restricted to protect important mussel assemblages. No-work areas will be located immediately downriver of abandoned Lock and Dam 1 (River Miles (RM) 53.9-54.1) and immediately upriver of the Holly Bluff Cutoff. Avoidance areas will be located immediately downriver of Bay Lake Run on the right descending bank (RM 71.6), upriver of abandoned Lock and Dam 1 on the left descending bank (LDB) (RM 53.9-54.1), and the upper 1 mile, LDB, of the channel excluded by the Holly Bluff Cutoff. Gravel (approximately 1 to 3 in. (2.54 to 7.62 cm) in diameter) would be placed in association with dike fields and weirs and at selected sites to augment existing gravel bars. If necessary, river banks opposite dike fields will be protected with gravel, riprap, and flood-tolerant vegetation.

The above improvement features were assembled into five plans that ranged from an estimated $249,808 to $1.3 million. The basic or original plan consisted of 116 separate features, affected 2.5 million square feet of aquatic habitat, and costs an estimated $1.3 million. Plan 2 was similar to Plan 1 except that weirs, possibly with limited value to mussels, were not included. Plans 3 and 4 eliminated habitat features from three reaches of the river with moderate to low mussel density. Plan 5, with an estimated cost of $249,808, included four three-dike fields and no weirs or revegetation. Gravel would only be placed in association with dike fields and at selected sites upriver and immediately downriver of an existing weir in the Holly Bluff Cutoff. Plan 5 would affect 665,000 sq ft of river bottom and contain 55 separate features.

The Team designed a 10-year monitoring plan that would assess physical and chemical conditions of water and sediment, measure density, species richness, species diversity, evenness, evidence of recent recruitment, and physical and reproductive condition of the freshwater mussels. Population and community parameters of fishes and non-molluscan invertebrates would also be assessed.